THE IMPACT OF HIGH PERFORMANCE TECHNOLOGY ON NAVAL SHIP DESIGN

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by

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ABSTRACT

High performance ships in general, are faster and more maneuverable than displacement ships of comparable size, while achieving parity in payload-carrying capacity. This performance results from the design and implementation of low-impact subsystems which allow the high performance ship to absorb the cost, in space and weight, of increased horsepower and the installation of a sustension system, the two major factors which contribute to the speed and seakeeping advantage. There are many differences in the design standards and requirements between high performance and displacement ships, arising from the high performance ship's low-impact subsystems. These differences can be identified and analyzed to determine the applicability, feasibility, and desirability of incorporating these high performance features in a displacement ship. The displacement ship designed to high performance standards would have the advantage of low-impact subsystem design without the attendant requirement of the high-impact sustension system. When this ship is compared to a conventional displacement ship, an assessment of the impact of high performance technology on Naval ship design can be made. This assessment is based on the additional weight and space made available to the high performance displacement ship for increased payload, the installation of more horsepower to provide higher speed, or the improvement of any of the other basic performance features of Naval ship design.

Thesis Supervisor: Clark Graham
Title: Associate Professor of Marine Systems

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NOMENCLATURE

W_n	Weight of a functional category, where n is a subscript defining the category
V_n	Volume of a functional category
M_n	Manning required for a functional category
E_n	Electrical energy required for a functional category

Definition of subscripts (n)

A	Auxiliaries
BH	Basic hull
C	Ship control
CD	Communications/Detection
E	Electrical
F	Fuel
FE	Electric plant fuel
FMP	Main propulsion fuel
H	Hull structure
HAB	Habitability
L	Personnel living
LFT	Lift
M	Personnel (manning)
MB	Mobility
MN	Maintenance
MP	Main propulsion
MS	Personnel stowage
OSO	Other ship operations
P	Payload
PM	Miscellaneous payload
S	Personnel support
SO	Ship operations
SS	Ship systems
SST	Superstructure
T	Tankage
W	Weapons

Numerical subscripts refer to either the Ship Work Breakdown Structure (SWBS)[11] if integer number; or the Proposed U.S. Navy Ship Space Classification System (SSCS)[2] if decimal number.

e.g., W_{241} = Weight of reduction gears

$V_{2.22}$ = Volume of food preparation and handling spaces

Δ	Full load displacement of ship, tons
D	Stores endurance period, days
KW	Installed electrical generation capacity, kilowatts
M	Total crew size, men
PC	Propulsive coefficient
R	Range at maximum sustained speed, nautical miles
SFC	Specific fuel consumption rate of main propulsion machinery, lb/HP-hr
SFCA	Specific fuel consumption rate of electric plant, lb/HP-hr
SHP	Shaft horsepower required to drive ship at maximum sustained speed, horsepower
SHP_I	Installed shaft horsepower
SHP_{MAR}	Shaft horsepower margin used in determining installed machinery requirements
TLPE	Tailpipe allowance for fuel requirements
V	Maximum sustained speed, knots
∇	Total enclosed volume of ship, cubic feet

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CHAPTER 1

INTRODUCTION

High performance ships in general have greater performance in both speed and seakeeping than their conventional displacement counterparts without sacrificing payload carrying capacity. This speed advantage in calm water is achieved largely through the design of subsystems which have low weight and volume requirements, allowing the high performance ship to carry more installed horsepower, thus increasing speed.

High speed and superior maneuverability in high sea states are hallmarks of high performance ships. This performance can be achieved by decoupling the influence of the sea on the hull by the incorporation of a specialized sustension system. Hydrofoils employ a foil system providing dynamic lift and eliminating the hull/water interface. Surface effect ships use an air cushion to remove the influence of waves on ship operation. It is this sustension system that provides the rough water advantage of high performance ships, and the low impact design of subsystems that contributes to the calm water advantage.

High performance ships, then, can achieve good payload capacity while absorbing the impact of the sustension system by saving weight and space in other design areas. Grostick, in reference 1, identified some of these design areas and stated that if the high performance standards were applied to a

displacement ship, the space and weight thus saved could be used for additional payload or the improvement of any other basic design feature. The level of analysis, however, was general, and no attempt was made to determine the feasibility of using these general high performance design indices in a displacement ship.

The purpose of this analysis, then, is to identify in detail the major design differences between high performance and displacement ships and to analyze the applicability, feasibility, and desirability of employing the high performance design features in a displacement ship design. Applying these high performance standards to a displacement ship may be beneficial by making more weight and volume available for other performance features, such as increased payload fraction, speed, or endurance. However, there will certainly be other performance tradeoffs that must be considered when using different standards and indices.

Since high performance ships must be designed to strict weight and volume requirements in order to be feasible, their design standards may reduce the luxury of operability found in many areas on displacement ships. However, since displacement designs are generally conservative, this reduction may not adversely affect the mission suitability of the ship.

The impact of high performance technology on Naval ship design is evaluated by performing several tasks. A comprehensive and consistent functional classification system is

developed to assist in the generation of the required parameters and design indices used in the impact study. The weights and volumes of a high performance ship and a similar displacement ship are grouped by functions, and parameters are developed from these functional categories. These design indices are analyzed in order to identify differences in design practice and to determine the reasons for these differences. An evaluation of the feasibility of applying the high performance design indices to the displacement design is then made.

Since high performance ships have superior speed in both calm and rough water, a meaningful impact study requires a matching of as many of the high performance design requirements as possible, including maximum speed, stores endurance period, and range at high speed. There are many design differences between high performance and displacement ships. If a systems analysis approach is to be applied, it would be helpful to reduce the number of these differences as much as possible in order to provide a more concise comparasion of the two types of ships.

This procedure can be applied to any high performance ship study, but hydrofoils were selected in this impact study, since they are the first generation of high performance ships, proven effective in actual operation, thus providing the most complete, accurate data base with which to work.

The general displacement ships considered were destroyer types and patrol boats. Traditionally, the destroyer has been the epitome of effectiveness at sea: fast, maneuverable, versatile, and potent. This is a relevant choice, since the thrust of high performance design is to produce a new generation of ships possessing the traditional destroyer capabilities.

CHAPTER 2

ANALYTICAL PROCEDURES

In order to determine the impact of high performance technology on Naval ship design, several tools must be developed. The first of these is a functional classification system for ship weights and volumes, energy and manning. This classification system is used in the development of the parameters or design indices which are used in the impact study. The parameters are generated in order to identify design differences between the high performance and displacement ships. They are also used to evaluate and quantify the differences in order to provide an assessment of the high performance impact.

The proper selection of ships is important in performing a meaningful impact study. A high performance ship and a displacement ship are chosen that have similar characteristics and mission requirements, if possible. Their weights and volumes are then broken down by function, the appropriate parameters or design indices are computed and compared, and the high performance parameters that can advantageously be applied to a displacement ship redesign are chosen.

A mathematical model is developed to facilitate the evaluation of the high performance impact. The desired parameters, design indices, and requirements are inputted, and the resulting payload weight and volume are computed. The

figure of merit selected in evaluating the high performance technological impact is that of payload weight and volume, defined here as the gross weight and volume remaining after all other functional requirements have been met. This is the budget allotted to the payload designer to use as he sees fit. In evaluating this available payload it must be realized that a portion of this weight and volume is needed for additional payload support: manning, electrical generation equipment and fuel, air conditioning, foundations, maintenance support equipment, and the like.

Section 2.1 - Functional Classification

There are many different methods used in classifying the functional areas of ships, among them the Bureau of Ships Consolidated Index (BSCI) and the Ship Work Breakdown Structure (SWBS).[11] Prior to the establishment of these standard classification systems, each ship designer used his own system or method of categorizing and classifying weight, volume, electrical energy allocation, and manning. In an impact study, it is mandatory that a unified, concise classification system be used in order to compare different ships on a common base. The system developed in this analysis incorporates a functional breakdown that provides the designer with the necessary information to determine the relative impact and importance of the various ship functions.

The ship is broken down into several broad functional categories:

- Payload
- Personnel
- Ship Operation
- Mobility
- Ship Systems
- Hull Structure
- Lift System

These categories are patterned roughly after the Proposed U.S. Navy Ship Space Classification Manual.[2] Each of these areas is subdivided further and is discussed individually. A detailed breakdown of each category is included in Appendix A.

2.1.1 - Payload

Payload is divided into three categories: communication/detection, weapons, and miscellaneous payload. Communication/detection spaces include the equipment and operating spaces for radio, secure communications, radar, sonar, and electronic maintenance. Communication/detection evaluation spaces, shops, stowage, and offices are also included here. Hardware items associated with communication/detection include command and control systems, exterior communications, surface and underwater surveillance systems, and electronic countermeasure equipment. The energy associated with

communication/detection is the electrical battle load of the equipment assigned to this category. The manning allocation is that part of the crew assigned to the communication/detection functions.

The weight and volume assigned to weapons include the launching, fire control, and ammunition handling systems for guns, missiles, torpedoes, mines, anti-submarine batteries, and countermeasures. Magazines and ammunition for the above systems are included. Aviation detachments are also part of the weapons category, including aircraft operations and control spaces, hangars, handling gear, maintenance spaces and equipment, aircraft stores, fuel, ammunition, and the aircraft themselves. Weapons energy and manning are those associated with the above systems.

Miscellaneous payload includes space and weight allotted to amphibious warfare, cargo transport, flag accommodations, passenger facilities and special missions. The appropriate electrical load and number of personnel are assigned to this category also.

2.1.2 - Personnel

Personnel is also broken down into three more specific areas: living, personnel support, and personnel stowage. This category encompasses everything required for dealing with the human presence aboard ship.

Living is comprised of the berthing, messing, and sanitary facilities for the crew. It includes staterooms, wardrooms, berthing compartments, mess decks, heads, and shower rooms. The weight of crew and effects, in addition to the outfit and furnishings of the above spaces, is included in the living category.

Personnel support includes the spaces and equipment for food preparation and handling, ship's administration, medical and dental treatment, personnel services, and recreation and welfare. Some of the spaces contained here are laundry rooms, tailor shops, ship's stores, barber shops, libraries, athletic gear lockers, and hobby shops.

Personnel stowage includes the spaces used for stowage of dry provisions, refrigerated provisions, general stores material, clothing and small stores, and chemical warfare equipment. Potable water tankage and stores conveyor trucks are also a part of personnel stowage. Among the weights assigned to this category are provisions and stores, and potable water.

The energy assigned to personnel may be considered to be the cruising electrical load, since it gives a better indication of energy usage than the battle load, because most personnel-related loads are non-essential and are stripped in the battle condition. Personnel assigned to this category include cooks, stewards, and yeomen.

2.1.3 - Ship Operations

There are five elements in the ship operations category. They consist of control, auxiliaries, electric plant, maintenance, and tankage. Control includes those areas of the ship dedicated to ship control, damage control, and non-administrative offices. Among the functions which are assigned to control are navigation systems, meteorological systems, telephone systems, and fire extinguishing systems. Outfit and furnishings for damage control stations also fall into this category.

Auxiliaries include spaces devoted to both engineering and deck auxiliaries. Included here is equipment for ventilation systems, air conditioning systems, compressed air systems, and anchor handling and stowage systems. Distilling plants, rudders, auxiliary boilers, steering and maneuvering systems, stabilizing fins, and mooring and towing systems are all part of the auxiliaries category. If a piece of auxiliary equipment is located in a main machinery space, a proportional volume of that space is assigned to auxiliaries, with the remaining volume assigned to main propulsion. Auxiliaries weights are similar to SWBS auxiliaries except that items which are distributed throughout the ship, such as vent ducting, are assigned to ship systems. Also, auxiliary systems dedicated to support of the machinery box, such as machinery space ventilation and auxiliary steam and drains within the machinery box, are assigned to main propulsion.

The electric plant category includes electric power generation equipment, switchgear and panels, power generation support systems, and degaussing equipment. Electrical control spaces, motor-generator rooms, and distribution equipment spaces are included in the electric plant category. As in the case of certain auxiliaries, a proportional volume is assigned to the electric plant for those pieces of equipment located in main machinery rooms. Cables, lighting, and other distributed weights, which are part of the SWBS electrical category, are assigned to ship systems. Rapair parts and special tools are assigned to maintenance.

Maintenance includes all shops and maintenance spaces devoted to repair and upkeep of mechanical and electrical equipments. Machine shops, interior communication shops, test laboratories, and general workshops are all part of the maintenance category. Among the weights assigned to maintenance are repair parts and special tools for the propulsion plant, electric plant, hull, auxiliary systems, and outfit and furnishings.

Tankage includes ballast tanks, peak tanks, voids, and unassigned spaces. Fixed or fluid ballast and ballasting systems are assigned to tankage also.

The energy required for ship operations is considered to be battle load, and personnel assigned include quartermasters and electrician's mates.

2.1.4 - Mobility

Main propulsion and fuel are the two areas that make up the mobility category. Main propulsion spaces include the machinery box, uptakes, and shaft alleys. Weights include all main propulsion machinery, the machinery space ventilation system, main propulsion control equipment and the auxiliary steam and drain system within the machinery box. Main propulsion weight closely correlates with SWBS main propulsion, with the exception of repair parts and tools, which are assigned to maintenance.

The fuel system consists of all tankage used for endurance fuel oil, reserve feed water, and lubricating oil. Tank heating systems and fuel compensating systems are included in this category.

The appropriate electrical battle load and personnel are applied to the mobility category.

2.1.5 - Ship Systems

The weights associated with ship systems are those which are distributed throughout the ship and are not readily identifiable with a particular space. Among these items are electrical power cable, ship's lighting, heating systems and ventilation ducting, auxiliary steam and drains outside the machinery box. Also included in ship systems are hull compartmentation, ship fittings, painting, deck covering, hull insulation, scuppers and deck drains, sheathing, and hull damping. Ship systems volume is that devoted to access and passageways.

2.1.6 - Hull Structure

There is no volume assigned to hull structure, since it is the containment vessel for the remaining functional categories and is the result of volume requirements, not a cause. The weights that fall into the hull structure category are shell and supporting structure, hull structural bulkheads, hull decks, hull platforms and flats, deck house structure, masts, kingposts, service platforms, foundations, and free flooding liquids. The weights assigned to hull structure correspond to the SWBS hull structure; except for ballast, which is assigned to tankage; and repair parts and tools, which fall into the maintenance category.

2.1.7 - Lift Systems

Contained in this category are spaces such as foil retraction machinery rooms, lift-fan rooms, and other spaces that are devoted to lift systems. Foils, struts, dedicated lift system prime movers, flexible seals, and skirts all contribute to the weight of this category.

Section 2.2 - Development of Parameters

Four general parameters or design indices are developed in this impact study: functional allocations, specific ratios, densities, and capacity-ship size ratios. They are briefly described below.

Functional allocations are the weight, volume, energy, and manning fractions of a functional category. The weight fraction is the functional weight divided by full load displacement; the volume fraction is the ratio of the functional volume to the total enclosed volume; energy fraction is the portion of the total installed generator capacity required by a function; and the manning fraction is the ratio of the functional manning requirement to total crew size.

Functional allocations provide an indication of the relative impact that subsystems or functional areas have on the whole ship. The relative priorities of the ship designer may also be reflected by the functional allocations. For example, if a naval architect designs a ship for speed, the mobility fractions may be high.

A functional category may have small functional allocations because of low ship impact or because another category may dominate, thus driving the relative impact of the first category down. For this reason another design index is necessary to help identify absolute ship impact. Specific ratios are suited to this task.

A specific ratio is the ratio of the "cost" of a function to its capacity; that is, the weight or volume required by a function divided by the useful output of that function. Specific ratios are much more informative than weight or volume fractions since they evaluate a functional impact on a normalized base. This normalization results in a more

meaningful comparison of functional impacts between ships, and the impact of high performance technology can more readily be assessed.

A <u>density</u> is the weight of a functional category divided by its volume. Functional densities are useful in assessing whether a ship is weight or volume limited and what features are causing the limitation. The density of a function may be high because it has a small volume or because its equipment is heavy or a combination of both. Because of this, the differences in functional densities between ships may be difficult to address. Payload density, however, may provide a good indication of whether armament is ordinance or electronics dominated. Vehicle density, the ratio of full load displacement to total enclosed volume, is an indication of space utilization efficiency.

A <u>capacity-ship size ratio</u> normalizes a functional capacity relative to ship size. It is the ratio of the capacity of a function to the full load displacement of the ship. It is an indication of the functional importance and the emphasis the function places on the design.

Parameters will have different levels of detail from ship to ship, depending on what depth of analysis is needed to ascertain why differences occur between ships. Since the level of detail will vary on a case basis, a complete listing would be much too cumbersome and unwieldy.

The major level 1 (most general) design indices are presented here by functional category. In the next chapter, the method of selection and use of more detailed parameters is presented. A complete listing of all the particular parameters used in this analysis is found in Appendix B.

2.2.1 - Payload Parameters

Table 1 lists some general parameters that may be used in a comparative analysis or impact study. There are no convenient specific ratios in the payload area, since weapons systems are so diverse. A payload capacity may be considered to be the number of launchers; but the type of launcher, its delivery capacity, response time, and effective range vary greatly from system to system. The true capacity of a payload is its mission accomplishment ability, and this is hard to quantify with different weapons systems and missions. Because of this, there is no meaningful capacity-ship size ratio in the payload area either. The ratio of number of weapons systems per ton of displacement is sometimes considered, but the wide disparity in the capabilities of different systems precludes an unbiased comparasion.

Since payload-carrying capability is the figure of merit in assessing the high performance impact, the depth of analysis of the payload area is not great. The important indices to be considered are payload weight fraction, payload volume fraction, and payload density.

TABLE 1

PAYLOAD PARAMETERS

DEFINITION	NAME	UNITS
W_P/Δ	Payload weight fraction	%
W_{CD}/Δ	Communications/Detection weight fraction	%
W_W/Δ	Weapons weight fraction	%
W_{PM}/Δ	Miscellaneous payload weight fraction	%
V_P/∇	Payload volume fraction	%
V_{CD}/∇	Communications/Detection volume fraction	%
V_W/∇	Weapons volume fraction	%
V_{PM}/∇	Miscellaneous payload volume fraction	%
E_P/KW	Payload energy fraction	%
E_{CD}/KW	Communication/Detection energy fraction	%
E_W/KW	Weapons energy fraction	%
E_{PM}/KW	Miscellaneous payload energy fraction	%
M_P/M	Payload personnel fraction	%
M_{CD}/M	Communications/Detection personnel fraction	%
M_W/M	Weapons personnel fraction	%
M_{PM}/M	Miscellaneous payload personnel fraction	%
W_P/V_P	Payload density	lb/ft^3
W_{CD}/V_{CD}	Communications/Detection density	lb/ft^3
W_W/V_W	Weapons density	lb/ft^3
W_{PM}/V_{PM}	Miscellaneous payload density	lb/ft^3

2.2.2 - Personnel Parameters

A listing of the personnel design indices is found in Table 2. The specific ratios are the important parameters in determining the personnel impact on a ship design. The habitability specific weight and volume are indicators of the cost per man in tons and cubic feet, for berthing, messing, sanitary, and support. The personnel stowage specific ratios give the impact of stores and provisions on a per man-per day basis. As these ratios become higher, the personnel impact will also increase. This impact can be lowered by either reducing crew size or storesendurance period, or by reducing the specific ratio.

2.2.3 - Ship Operations Parameters

Table 3 provides the level 1 parameters in the ship operations category. The major contributors toward the impact of ship operations are auxiliaries and the electric plant. Tankage, maintenance, and control individually usually play minor roles, and they can therefore be combined under the heading of "other ship operations".

The specific ratios assigned to auxiliaries employ total enclosed volume as the capacity of the function. This choice was made because most of the elements assigned to auxiliaries are strongly influenced by the total enclosed volume of a ship: ventilation, air conditioning, and heating to name a few. The auxiliaries specific ratios, then, give an indication of the cost of supplying auxiliary services to the ship.

TABLE 2

PERSONNEL PARAMETERS

DEFINITION	NAME	UNITS
W_M/Δ	Personnel weight fraction	%
W_L/Δ	Living weight fraction	%
W_S/Δ	Personnel support weight fraction	%
W_{MS}/Δ	Personnel stowage weight fraction	%
V_M/∇	Personnel volume fraction	%
V_L/∇	Living volume fraction	%
V_S/∇	Personnel support volume fraction	%
V_{MS}/∇	Personnel stowage volume fraction	%
E_M/KW	Personnel energy fraction	%
E_L/KW	Living energy fraction	%
E_S/KW	Personnel support energy fraction	%
E_{MS}/KW	Personnel stowage energy fraction	%
M_M/M	Personnel personnel fraction	%
M_S/M	Personnel support personnel fraction	%
M_{MS}/M	Personnel stowage personnel fraction	%
W_M/M	Personnel specific weight	lb/man
W_{HAB}/M	Habitability specific weight	lb/man
$W_{MS}/(MxD)$	Personnel stowage specific weight	lb/man-day
V_M/M	Personnel specific volume	ft^3/men
V_{HAB}/M	Habitability specific volume	ft^3/man
$V_{MS}/(MxD)$	Personnel stowage specific volume	ft^3/man-day
W_M/V_M	Personnel density	lb/ft^3
W_{HAB}/V_{HAB}	Habitability density	lb/ft^3
W_{MS}/V_{MS}	Personnel stowage density	lb/ft^3
M/Δ	Personnel capacity-ship size ratio	men/ton

TABLE 3

SHIP OPERATIONS PARAMETERS

DEFINITION	NAME	UNITS
W_{SO}/Δ	Ship operations weight fraction	%
W_A/Δ	Auxiliary weight fraction	%
W_E/Δ	Electric plant weight fraction	%
W_{OSO}/Δ	Other ship operations weight fraction	%
V_{SO}/∇	Ship operations volume fraction	%
V_A/∇	Auxiliaries volume fraction	%
V_E/∇	Electric plant volume fraction	%
V_{OSO}/∇	Other ship operations volume fraction	%
E_{SO}/KW	Ship operations energy fraction	%
E_A/KW	Auxiliaries energy fraction	%
E_E/KW	Electric plant energy fraction	%
E_{OSO}/KW	Other ship operations energy fraction	%
M_{SO}/M	Ship operations personnel fraction	%
M_A/M	Auxiliaries personnel fraction	%
M_E/M	Electric plant personnel fraction	%
M_{OSO}/M	Other ship operations personnel fraction	%
W_{SO}/∇	Ship operations specific weight	lb/ft^3
W_A/∇	Auxiliaries specific weight	lb/ft^3
W_E/KW	Electric plant specific weight	lb/kilowatt
W_{OSO}/∇	Other ship operations specific weight	lb/ft^3
V_{SO}/∇	Ship operations specific volume	ft^3/ft^3
V_A/∇	Auxiliaries specific volume	ft^3/ft^3
V_E/KW	Electric plant specific volume	ft^3/KW

V_{OSO}/∇	Other ship operations specific volume	ft^3/ft^3
W_{SO}/V_{SO}	Ship operations density	lb/ft^3
W_A/V_A	Auxiliaries density	lb/ft^3
W_E/V_E	Electric plant density	lb/ft^3
W_{OSO}/V_{OSO}	Other ship operations density	lb/ft^3
KW/Δ	Electrical capacity-ship size ratio	$\frac{\text{kilowatts}}{\text{ton}}$

The electric plant specific ratios provide the space and weight impact of the installed electrical generation capacity. They can indicate the type of machinery used for prime mover, the type of power generated, and the size of the maintenance and access envelope around the electric plant.

Since the category of other ship operations extends throughout the ship in the form of tankage, workshops, and other features, the appropriate capacity is that of total enclosed volume.

2.2.4 - Mobility Parameters

The general mobility parameters that may be used in an impact study are included in Table 4. The main propulsion specific ratios are useful in determining the weight and volume impact of the main propulsion machinery. If the specific ratio is decreased in a design, either main propulsion will have a smaller impact, or more shaft horsepower can be installed while maintaining the same impact. The fuel system density may be used to indicate the volume impact of fuel tankage on a design. A high value of fuel system density may indicate the efficient use of volume available for fuel tankage.

2.2.5 - Ship Systems Parameters

Table 5 lists the level 1 parameters used in analyzing ship systems. The specific ratios use total enclosed volume as their capacity, since the ship systems category is

TABLE 4

MOBILITY PARAMETERS

DEFINITION	NAME	UNITS
W_{MB}/Δ	Mobility weight fraction	%
W_{MP}/Δ	Main propulsion weight fraction	%
W_F/Δ	Fuel system weight fraction	%
V_{MB}/∇	Mobility volume fraction	%
V_{MP}/∇	Main propulsion volume fraction	%
V_F/∇	Fuel system volume fraction	%
E_{MB}/KW	Mobility energy fraction	%
E_{MP}/KW	Main propulsion energy fraction	%
E_F/KW	Fuel system energy fraction	%
M_{MB}/M	Mobility personnel fraction	%
M_{MP}/M	Main propulsion personnel fraction	%
M_F/M	Fuel system personnel fraction	%
W_{MP}/SHP_I	Main propulsion specific weight	lb/SHP
V_{MP}/SHP_I	Main propulsion specific volume	ft^3/SHP
W_{MB}/V_{MB}	Mobility density	lb/ft^3
W_{MP}/V_{MP}	Main propulsion density	lb/ft^3
W_F/V_F	Fuel system density	lb/ft^3
SHP_I/Δ	Main propulsion capacity-ship size ratio	SHP/ton

TABLE 5

SHIP SYSTEMS AND HULL STRUCTURE PARAMETERS

DEFINITION	NAME	UNITS
Ship Systems		
W_{SS}/Δ	Ship systems weight fraction	%
V_{SS}/∇	Ship systems volume fraction	%
W_{SS}/∇	Ship systems specific weight	lb/ft^3
V_{SS}/∇	Ship systems specific volume	ft^3/ft^3
Hull Structure		
W_H/Δ	Hull structure weight fraction	%
W_H/∇	Hull structure specific weight	lb/ft^3

distributed throughout the ship. Along with auxiliaries and other ship operations, the ship systems specific ratios provide an indication of the cost associated with adding to the total enclosed volume of a ship.

2.2.6 - Hull Structure Parameters

The two general structural parameters are also presented in Table 5. The hull structure specific weight is the ratio of the structural weight to the total enclosed volume of the ship. It can be an indication of the structural loading demands, the construction or fabrication techniques, or the structural material of the hull. It also provides an assessment of the impact of enclosed volume on a ship design.

Section 2.3 - Impact Model

A mathematical model is developed to facilitate an assessment of the high performance technology when applied to a displacement ship design. It is a parametric model used to reallocate the weights and volumes of the various functional categories in order to determine the resultant figure of merit: payload weight and volume. The inputs to the model are the performance requirements established for the re-designed ship, including maximum speed, stores endurance period, and range at maximum speed. This is necessary in order to reduce the number of design differences between the two ships, thus providing a more meaningful evaluation of the figure of merit. Most of the selected parameters used

in the model are specific ratios, since these most readily translate performance requirements and capacities into the weights and volumes necessary to accommodate them.

The model is used for analysis rather than synthesis, being a parametric tool employed to reallocate weight and volume within a ship of fixed displacement. The model computes the weights required for all of the functional categories except payload. The difference between the sum of these weights and the displacement is then considered to be the payload weight. A total enclosed volume is estimated and used in computing those functions which are volume dependent, e.g., auxiliaries weight and volume. After the functional volumes are evaluated, they are subtracted from the estimated total enclosed volume to determine the payload volume.

There are several options that can be used when working with the model. The first option inputs a required payload density, ensuring a balanced payload output. If the initial total enclosed volume estimate results in an unsatisfactory payload density, it is incremented, and the payload weight and volume are recalculated. Iterations continue until the payload density requirement is met.

Another option is to specify the vehicle density of the redesigned ship. This will fix the total enclosed volume of the ship and result in a payload weight and volume that may not have a desirable density. Since the figure of merit represents the payload designer's budget, however, an assessment of the practicality need not be made.

A third option would be to input both the vehicle density and the payload weight and volume fractions, and to calculate the resulting weight and volume made available for mobility. The maximum horsepower, and hence, the speed, that can be accommodated by the redesigned ship is then computed. This procedure entails a balancing of weight and volume required for main propulsion and fuel and determining whether the available mobility weight or volume is limiting.

The flow chart developed for the impact model is provided by Figure 1.

2.3.1 - Payload Weight

Four of the functional weights are dependent on the total enclosed volume that was estimated for the ship. They are ship systems weight, auxiliaries weight, other ship operations weight, and hull structure weight. The equations used to find these weights are listed below:

$$W_{SS} = (W_{SS}/\nabla) \times \nabla$$

$$W_{A} = (W_{A}/\nabla) \times \nabla$$

$$W_{OSO} = (W_{OSO}/\nabla) \times \nabla$$

$$W_{H} = (W_{H}/\nabla) \times \nabla$$

The weights associated with personnel are driven by both crew size and stores endurance period:

$$W_{MS} = [W_{MS}/(M \times D)] \times M \times D$$

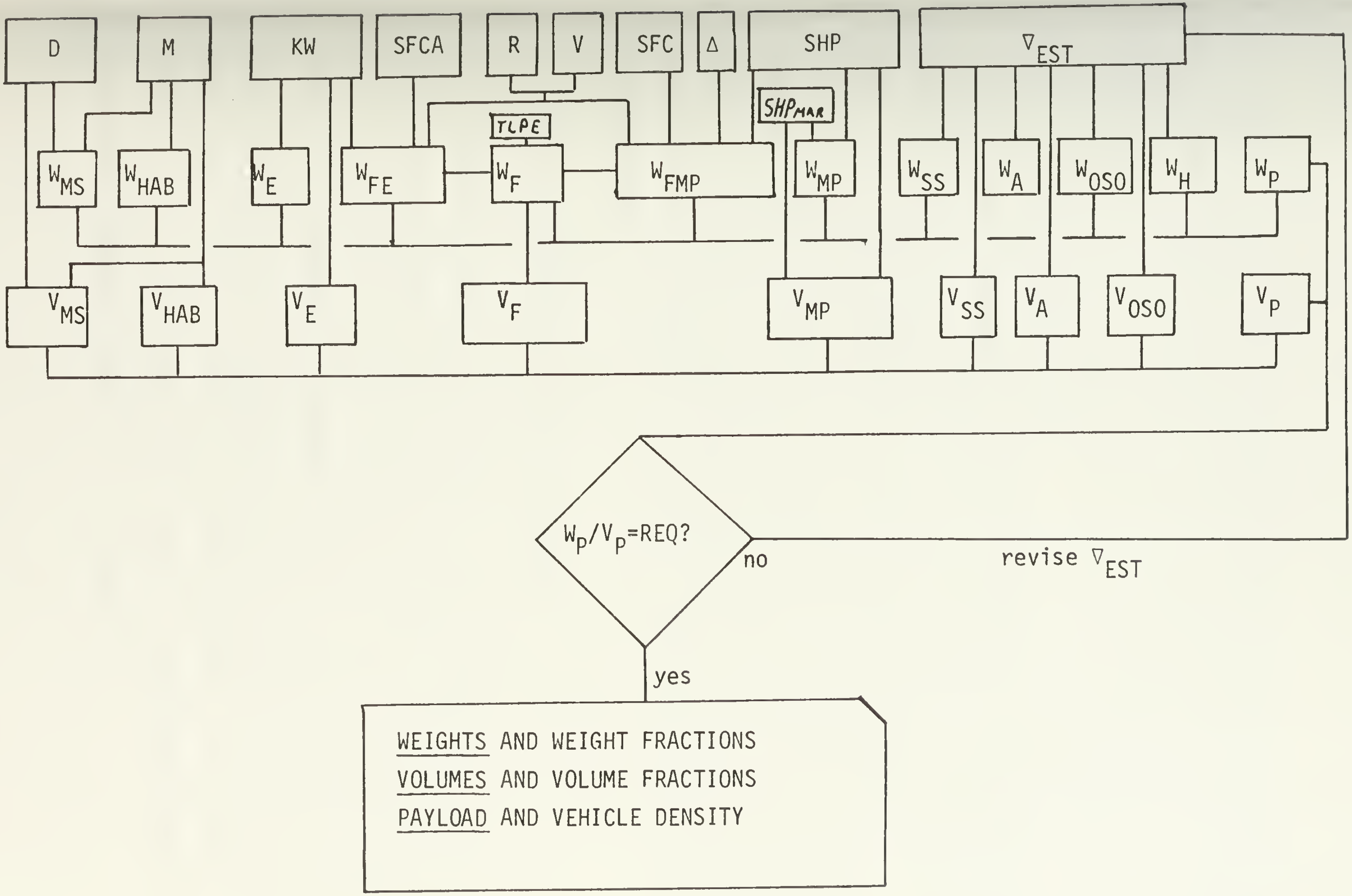

FIGURE 1 - IMPACT MODEL FLOW CHART

$$W_{HAB} = (W_{HAB}/M) \times M$$

The electric plant weight is found by multiplying the installed generation capacity by the electric plant specific weight:

$$W_E = (W_E/KW) \times KW$$

The main propulsion weight is developed from the shaft horsepower required to drive the ship at maximum sustained speed, the shaft horsepower margin used in determining installation requirements, and the main propulsion specific weight. The model does not calculate the shaft horsepower required for maximum sustained speed; but, like the speed and range, is an input to the model. The equation used is included here.

$$W_{MP} = (W_{MP}/SHP_I) \times SHP \times SHP_{MAR}$$

The value that results is based on the assumption that power plants are available in continuous sizes. This is not the case for gas turbine main propulsion units, the type used in most high performance designs and many displacement ships. This fact must be considered in analyzing the resulting payload weight, and is one of the limitations of the model. However, in a conceptual ship design, this approximation for propulsion machinery weight is reasonable.

Fuel weight is determined from both the electric plant and the main propulsion requirements. The fuel demanded by the electric plant is controlled by the specific fuel consumption rate of its prime mover, the capacity of the generators, and the expected operating endurance. The operating time is determined from the ship's maximum sustained speed, and the range required at that speed. Since fuel requirements for high performance ships are based on range at high speed, this time is used for the electric plant demand. The equation used for determining electric plant fuel is listed below:

$$W_{FE} = \frac{KW \times SFCA \times R}{V} \times \frac{1.34}{2240}$$

The assumed generator efficiency is not included, since the fuel estimate is based on the total installed generator capacity and not the actual loads encountered.

The fuel weight fractions of high performance ships are large due to the speed and range requirements. In these cases, the Brequet range equation can be used to predict the necessary main propulsion fuel weight. This equation takes into account the reduction in displacement due to fuel burnup and the corresponding reduction in the shaft horsepower required to maintain speed.

$$RB = \left(\frac{2240 \times \Delta \times V}{SFC \times SHP}\right) \ln \left(\frac{\Delta}{\Delta - W_{FMP}}\right)$$

Where

RB = Brequet Range, (nautical miles)

SFC = Prime Mover Specific Fuel Consumption Rate, (lbs/SHP-hours)

Δ = Full Load Displacement, (tons)

SHP = Shaft Horsepower Required to Maintain Maximum Sustained Speed

V = Maximum Sustained Speed, (knots)

W_{FMP} = Main Propulsion Fuel Weight, (tons)

Figure 2 shows the importance in using the Brequet range when estimating high performance fuel weight. For example, if a ship has a fuel weight fraction of 35%, the range is increased by almost 20%.

The equation used for main propulsion fuel weight is derived from the Brequet range equation.

$$W_{FMP} = \Delta \ [1 - \exp \ (-\frac{R \times SHP \times SFC}{\Delta \times V \times 2240})]$$

The electric plant and main propulsion weights are added together and the sum is divided by an appropriate tail-pipe allowance which accounts for unuseable fuel caused by tank shape and suction line location.

$$W_F = \frac{W_{FE} + W_{FMP}}{TLPE}$$

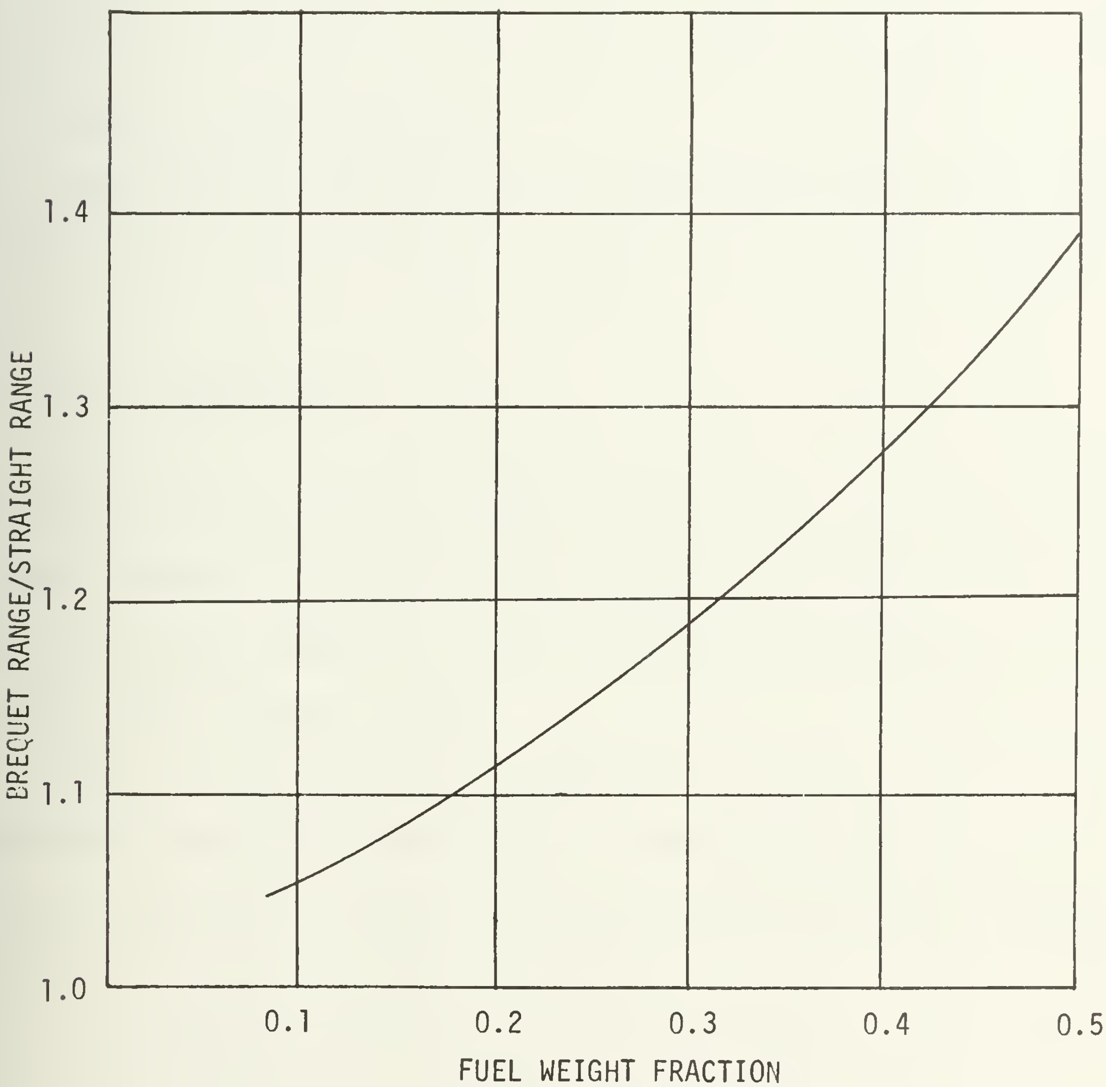

FIGURE 2 - BREQUET RANGE CORRECTION BASED ON FUEL FRACTION

The payload weight, then, is the difference between the full load displacement and the sum of the other functional weights.

$$W_P = \Delta - \Sigma W_n$$

2.3.2 - Payload Volume

The fuel system volume is estimated from the fuel system density and the fuel system weight.

$$V_F = W_F/(W_F/V_F)$$

Since the fuel system density already takes into account tank shape, overflow prevention allowance, and piping runs and baffles within tanks, no other factors are necessary to predict fuel system volume.

Three of the functional volumes are influenced by the estimated total enclosed volume. They are ship systems volume, auxiliary volume, and other ship operations volume.

$$V_{SS} = (V_{SS}/\nabla) \times \nabla$$

$$V_A = (V_A/\nabla) \times \nabla$$

$$V_{OSO} = (V_{OSO}/\nabla) \times \nabla$$

The remaining volume allocations are computed from their respective specific volumes:

$$V_{MS} = [V_{MS}/(MxD)] \times M \times D$$

$$V_{HAB} = (V_{HAB}/M) \times M$$

$$V_E = (V_E/KW) \times KW$$

$$V_{MP} = (V_{MP}/SHP_I) \times SHP \times SHP_{MAR}$$

The portion of the estimated total enclosed volume remaining after all other functional requirements have been met is considered to be the payload volume.

$$V_P = \nabla - \Sigma V_n$$

If the payload volume does not provide a satisfactory payload density, then the estimated total enclosed volume is adjusted and the functional allocations are recomputed.

<u>2.3.3 - Limitations of the Impact Model</u>

The impact model assumes that a weight or volume reduction in one functional area can be applied directly to any other area. This is perhaps the most important assumption made by the model, and, consequently, limits its validity. The model does not account for longitudinal weight distribution or the

resulting structural loading and longitudinal stability. It does not take into account the resultant transverse stability of the redesigned ship, but this area will be addressed in the next section. The resultant weight and volume estimates of the functional areas assume that subsystems can be designed as continuous functions. This assumption is least valid in the area of main propulsion, prime movers being available only in discrete capacities. The resultant payload weight and volume represent the "gross" payload. A significant amount of this space and weight is required for additional support items, including manning, electrical power generation, and fuel.

The model does, however, provide a quantitative measure of the impact of employing high performance standards and design criteria in a displacement ship.

Section 2.4 - Vertical Moment Analysis

Because the impact model redistributes the full load displacement among the functional categories, the vertical moment of the ship and, consequently, its hydrostatic stability may change. A vertical moment analysis is performed to determine the required location of additional weight made available for payload to maintain constant vertical moment.

The vertical center of gravity (VCG) of a functional category is considered to be equal to that of the dominant weight group(s) in that category. Table 6 lists the SWBS weight groups from which the VCG's are to be extracted for each functional category.

TABLE 6

VERTICAL CENTERS OF GRAVITY ASSIGNED TO FUNCTIONAL CATEGORIES

Functional Category	VCG of Weight Group
Hull Structure	100
Main Propulsion	200
Electric Plant	300
Auxiliaries	500
Personnel	600, crew and effects
Payload	400, 700, ammunition
Fuel	Fuel
Other Ship Operations	Light Ship
Ship Systems	Light Ship

For each functional category, the difference in weight between the original ship and the redesigned one is multiplied by the displacement ship's moment arm to obtain the change in vertical moment. The total change in moment is then divided by the additional payload weight of the redesigned ship to determine the vertical location of the center of gravity of the payload. If the payload is positioned at this height, the stability characteristics of the redesigned ship will be identical to that of the original ship. This payload location, like the payload weight and volume, is considered to be part of the designer's budget.

CHAPTER 3

ANALYSIS OF HIGH PERFORMANCE AND DISPLACEMENT SHIPS

It is the purpose of this chapter to present a detailed method of analyzing and comparing high performance and displacement ships by implementing the tools developed in the last chapter. This analysis is conducted to identify differences in design requirements and parameters between the ship types. When these differences have been quantified, an assessment is made to determine the applicability, feasibility, and desirability of incorporating the high performance design indices in the displacement ship.

In order to conduct a meaningful impact study of high performance technology, attention must be paid to the proper selection of the ships used in the analysis. The criteria established for the selection of the ships and the choices made are contained in Section 3.1. The method of analysis and the results are presented in Section 3.2. Each functional category was analyzed individually; the results are presented in order of decreasing ship impact. An overall summary and conclusions of the analysis are provided in Section 3.3.

Section 3.1 - Selection of Ships

Hydrofoils were selected as the high performance ships since they have been proven effective in actual operation, providing the most complete, accurate data base with which to work. Displacement ships considered were destroyer-types

and small patrol gunboats. A pair of small ships and a pair of large ships were analyzed in order to provide results over a wide range of displacements. Several guidelines were used in the selection of each pair:

- modern design
- fully combatant
- sufficient design data available
- similar in size and mission capability

3.1.1 - Small Ships

The hydrofoil chosen was the U.S. Variant of the NATO hydrofoil (PHM), a 231 ton, single-mission-area, gas-turbine-powered ship with small crew, high speed, and limited endurance. The PHM is scheduled to be operational in the U.S. fleet in 1977. It is of all-aluminum construction and is capable of speeds in excess of 40 knots.

The displacement counterpart selected was the PG-84 class patrol gunboat, operational since the mid-1960's, but with a similar mission capability. It was the Navy's first combatant ship with gas turbine propulsion and aluminum hull construction. PG-84 displaces 242 tons and is capable of calm water speeds of about 40 knots, making it comparable to PHM in these two areas. Table 7 provides a listing of the general characteristics of the two ships.

TABLE 7

SMALL SHIP CHARACTERISTICS

	PG-84[3]	PHM[3]
Displacement (tons)	242	231
Length	164.5	130
Beam	23.8	29
Draft	9.5	9.5
Main Engines	2 Diesel/1 GT, 14750 SHP CODOG	2 Diesel/1 GT, 17340 SHP CODOG
Propulsor	2 CRPP propellers	Waterjet
Electric Plant	Diesel 60 HZ 200 KW	GT 400 HZ 400 KW
Speed (knots)	~40 knots	40+ knots
Range (M.M.)	500 @ ~40 kts. (est)	700 @ 40+ knots (est)
Complement	24	21
Payload	3"/50 cal gun Standard missile or 40 mm gun MK 87 FCS	76 mm OTO Melara gun Harpoon missile MK 94 FCS

NOTE: The range estimates were based on typical speed-power curves for similar displacement ships and hydrofoils.

3.1.2 - Large Ships

In order to meet the guidelines established for ship selection, the large hydrofoil chosen was a conceptual design of a 1276 ton, open-ocean capable ship, the Hydrofoil Ocean Combatant (HOC). It is the result of a Naval Ship Engineering Center study of a multimission ship with a high speed endurance sufficient for ocean crossings. It is gas turbine powered and of all-aluminum construction.

The displacement ship chosen was the new class of guided missile frigates (FFG-7), also gas turbine powered and with mission capabilities similar to HOC's. There is a large disparity in size and speed between these two designs, however. FFG-7 displaces 3585 tons and has a maximum speed of under 30 knots. It was still chosen, though, because there are no recent designs in the 1200-1300 ton displacement range, and FFG-7 does provide a design that embodies the most current displacement ship practices. The important characteristics of FFG-7 and HOC are found in Table 8.

Section 3.2 - Functional Comparasion

The functional weights and volumes were calculated for the four ships and are listed for reference in Appendix C. The analysis of each functional category will be presented individually, beginning with those categories which have significant ship impact, and those where there are large differences between the design indices of the hydrofoil and the displacement ship. Within each category, the small

TABLE 8

LARGE SHIP CHARACTERISTICS

	FFG-7[3]	HOC[4]
Displacement (tons)	3585	1275.9
Length (ft)	445	227.5
Beam (ft)	45	56.0
Draft (ft)	24.5	11.5
Main Engines	2 GT, 40,000 SHP	2 GT/2 GT, 47,000 SHP COGOG
Electric Plant	4 diesel generators 60 HZ, 4000 KW	GT generators 60 HZ, 1500 KW
Propulsor	Propeller	Propeller
Speed (kts)	28+	40+
Range (N.M.)	2000 @ 28+ kts (est)	2500 @ 40+ kts (est)
Complement	176	87
Payload	1-76MM OTO Melara gun	2-MK 32 torpedo tubes
	1-MK13 missile launcher	20-SM-2 vertical launchers
	2-SH2D LAMPS helos	2-PHM type Harpoon launchers
	2-MK32 triple torpedo tubes	1-NATO Sea Sparrow launcher
	1-20MM CIWS	ETAS and APRAPS towed sonar
	SQS-56 Sonar	MK74 FCS
	MK92FCS	SPS-52 radar
	SPS-55 radar	SPS-55 radar
	SPS-49 radar	SPS-58 radar
	NTDS suit	

NOTE: The range estimates were based on typical speed-power curves for similar displacement ships and hydrofoils.

ships will be discussed first, and then the large ships. In general, the depth of analysis will be greater in the case of the small ships, because their designs are complete and the data bases are more detailed.

Each pair of ships will be analyzed at succeeding levels of detail in order to determine the reasons for major differences in their design indices. The appropriate specific ratios are then selected and applied to the displacement ship in order to determine the high performance impact of each particular functional category. The total impact of high performance technology on Naval ship design will be presented in Chapter 4.

Figures 3 through 6 are graphic representations of the weight and volume allocations that were computed for each of the four ships. They readily display the impact of the foil system on the high performance ships.

As shown by the figures, one-eighth of PHM's full load displacement is required for the foil system, but its payload weight fraction is still higher than PG-84's. This is accomplished by the low relative impacts of other functional categories, primarily main propulsion, hull structure, ship systems, and other ship operations.

HOC's foil system demands 18.5% of its full load displacement; fuel accounts for another 32.1% to accommodate its speed and endurance requirements; but in spite of these significant impacts, its payload weight fraction is still

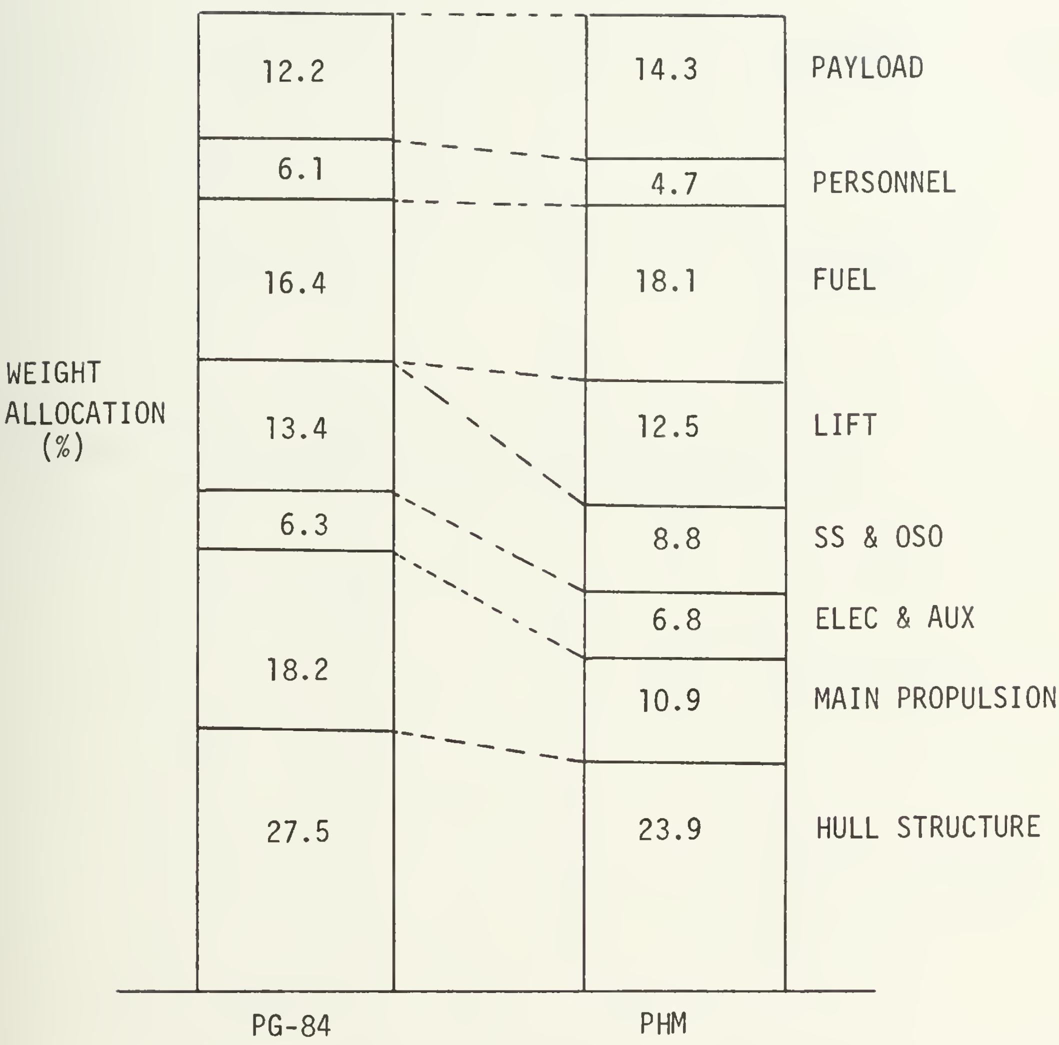

FIGURE 3 - COMPARISON OF WEIGHT ALLOCATIONS - SMALL SHIPS

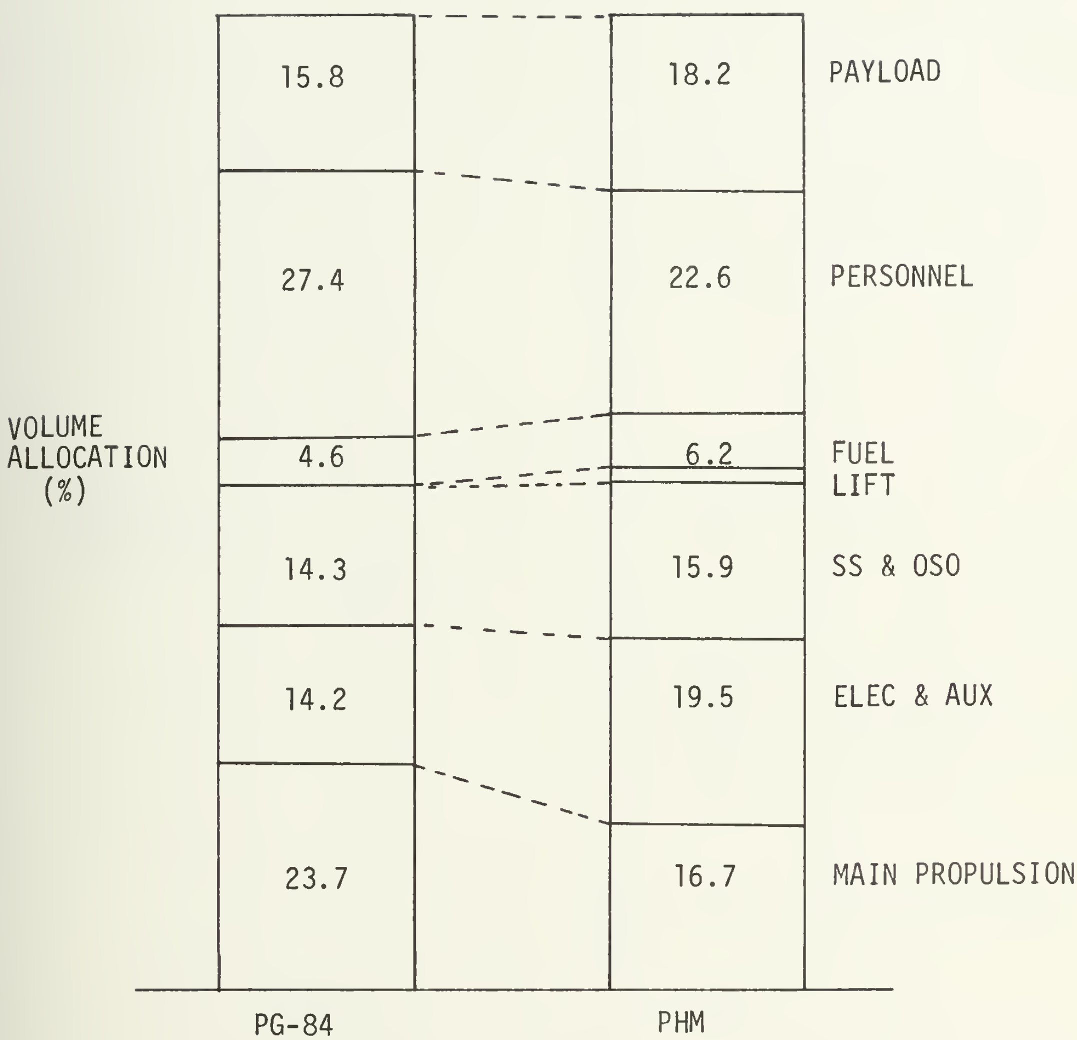

FIGURE 4 - COMPARISON OF VOLUME ALLOCATIONS - SMALL SHIPS

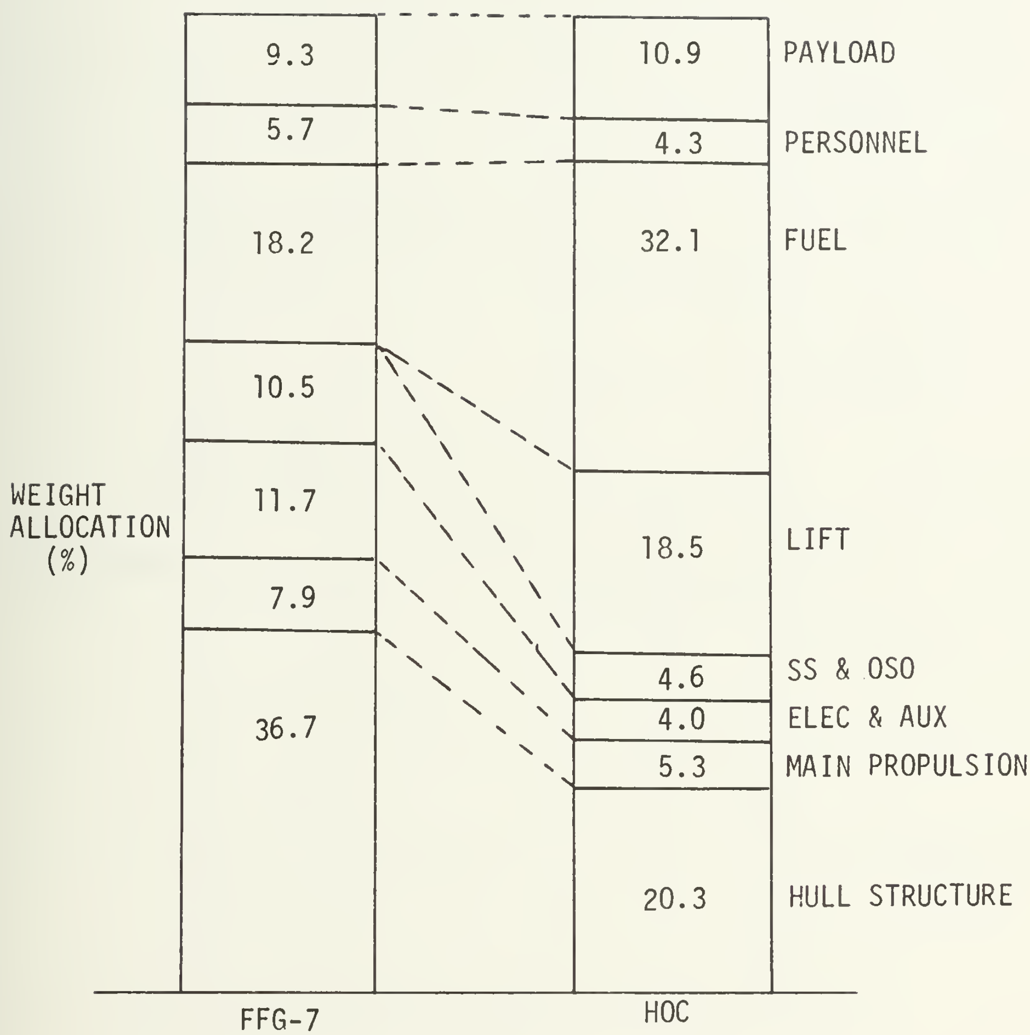

FIGURE 5 - COMPARISON OF WEIGHT ALLOCATIONS - LARGE SHIPS

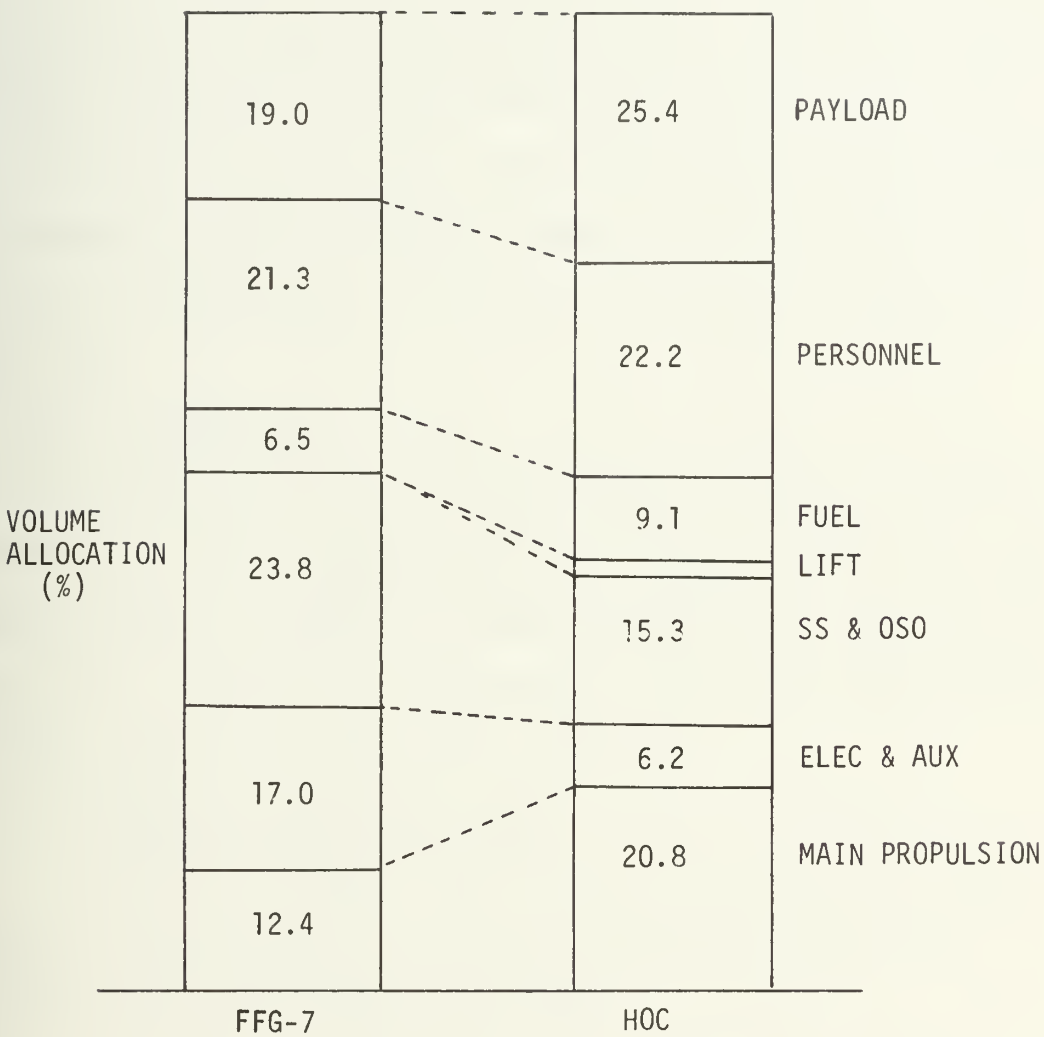

FIGURE 6 - COMPARISON OF VOLUME ALLOCATIONS - LARGE SHIPS

higher than FFG-7's. The high performance technology that allows this apparent advantage in the figure of merit will be analyzed in the following subsections.

The payload volume fractions are also larger in the hydrofoils than in the displacement ships, due to the relatively low volume impacts of several other functional categories.

The specific ratios that were developed in this analysis and discussed in the following subsections are graphically presented for reference in Figures 7 through 10, beginning on page 115.

3.2.1 - Mobility

The area of mobility is one in which there are significant differences in the standards and performance of the high performance ships as compared to their displacement counterparts. Table 9 is a listing of the important mobility characteristics and design indices of each ship analyzed.

3.2.1.1 - PG-84 vs. PHM

The first major difference between the two ships is found in the weight and volume fractions of the main propulsion plant and the fuel system:

	PG-84	PHM
Mobility wt. fr. W_{MB}/Δ	34.6%	29.0%
Main prop. wt. fr. W_{MP}/Δ	18.2%	10.8%
Fuel sys. wt. fr. W_F/Δ	16.4%	18.1%
Mobility vol. fr. V_{MB}/∇	28.3%	23.0%
Main prop. vol. fr. V_{MP}/∇	23.7%	16.7%
Fuel sys. vol. fr. V_F/∇	4.6%	6.2%

TABLE 9

MOBILITY CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_{MB}/Δ	%	34.6	29.0	26.1	37.4
W_{MP}/Δ	%	18.2	10.8	7.9	5.3
W_F/Δ	%	16.4	18.1	18.2	32.1
V_{MB}/∇	%	28.3	23.0	18.9	29.9
V_{MP}/∇	%	23.7	16.7	12.4	20.8
V_F/∇	%	4.6	6.2	6.5	9.1
E_{MB}/KW	%	.7	.7	--	--
M_{MB}/M	%	16.7	14.3	6.3	--
W_{MP}/SHP_I	lb/SHP	6.67	3.24	15.80	3.24
W_{230}/SHP_I	lb/SHP	1.52	1.29	3.49	.86
W_{240}/SHP_I	lb/SHP	3.41	1.11	7.72	1.58
W_{241}/SHP_I	lb/SHP	1.36	.35	3.07	.82
W_{242}/SHP_I	lb/SHP	.25	.02	0	.02
$W_{243-247}/SHP_I$	lb/SHP	1.81	.75	4.65	.74
$W_{250-260}/SHP_I$	lb/SHP	1.42	.53	2.61	.52
W_{298}/SHP_I	lb/SHP	.03	.26	.84	.23
V_{MP}/SHP_I	ft^3/SHP	.78	.44	1.60	1.00
W_{230}	tons	9.98	9.97	62.36	18.0
W_{240}	tons	22.47	8.63	137.9	33.2
W_{241}	tons	8.95	2.69	54.83	17.2
W_{242}	tons	1.65	.17	0	.5
$W_{243-247}$	tons	11.90	5.78	83.07	15.5
$W_{250-260}$	tons	9.37	4.11	46.67	11.0
W_{298}	tons	.20	2.01	15.08	4.9

Item	Units	PG-84	PHM	FFG-7	HOC
SHP_I	SHP	14750	17340	40000	47000
V	knots	~40	40+	28+	40+
R	n.m.	500(est)	700(est)	2000(est)	2500(est)
M_{MB}	men	4	3	11	--
E_{MB}	KW	1.32	2.6	--	--
PC	--	.6[1]	.53[5]	.65[8]	.625[4]
SFC	lb/SHP-hr	.48[6]	.43[7]	.43[7]	.43[7]
SHP_I/Δ	SHP/ton	60.99	74.96	11.16	36.84
EHP @ V	HP	7800	5180	20800	25000
W_F/V_F	lb/ft^3	39.73	33.08	43.84	44.25

NOTE: Names of design indices are included in Appendix B.

PHM has appreciably lower mobility weight and volume fractions than PG-84. Several factors could account for a low mobility impact, including maximum speed, range, installed horsepower, and propulsive coefficient. PHM's main propulsion capacity-ship size ratio is more than 20% higher than PG-84's, however, indicating higher speed, and since displacements are comparable, more horsepower. But in spite of a greater maximum speed and more installed horsepower, PHM's main propulsion weight and volume fractions are both significantly lower than PG-84's. The reason must lie with the specific ratios:

		PG-84	PHM
Main prop. sp. wt.	W_{MP}/SHP_I	6.67 lb/SHP	3.24 lb/SHP
Main prop. sp. vol.	V_{MP}/SHP_I	0.78 ft^3/SHP	0.44 ft^3/SHP

PHM's main propulsion specific weight is less than half that of PG-84's. This can only result from the use of a considerably lighter weight main propulsion plant. An analysis of the propulsion plant is necessary to determine the reasons for this difference and will be presented when the next level of detail is discussed. The main propulsion specific volume is lower in PHM, due to the compactness of the high performance design. This difference reflects the necessity of volume consciousness in a high performance ship design.

The fuel fractions are higher in PHM, however. The dominant reason for this is that PHM has a higher sustained speed, more horsepower, and longer range at maximum speed than PG-84. Other reasons may include differences in specific fuel consumption rate and propulsive coefficient.

The mobility energy fractions show that PG-84 and PHM have equal fractional demands upon their respective electrical generation capacity: 0.7%. This is to be expected, since both ships have similar prime movers.

Mobility manning is lower in PHM, due mainly to the fact that personnel have a large weight and volume impact, and mobility manning is limited to an essential number.

Level 2

Further analysis is necessary to determine the reasons for the difference in the main propulsion specific weight. The following parameters are needed:

		PG-84	PHM
Prime mover sp. wt.	W_{230}/SHP_I	1.52 lb/SHP	1.29 lb/SHP
Transmission sp. wt.	W_{240}/SHP_I	3.41 lb/SHP	1.11 lb/SHP
Support sys. sp. wt.	$W_{250-260}/SHP_I$	1.42 lb/SHP	0.53 lb/SHP
Oper. fl. sp. wt.	W_{298}/SHP_I	0.03 lb/SHP	0.26 lb/SHP

Significant differences occur in all areas except the prime mover specific weight, which is comparable for the two ships since similar prime movers are used in both. PHM employs waterjet propulsion, which is the principal reason

for both the lower transmission specific weight and the higher operating fluids specific weight. The entrained water in a jet propulsor must be considered as part of the main propulsion weight (operating fluid), and consequently, the operating fluids specific weight will be higher than in the case of a propeller-driven ship. The transmission specific weight will be analyzed further in later discussion.

The support systems specific weight is lower, primarily because the waterjet propulsor and transmission require less support in the areas of propulsion control and lubricating oil.

Level 3

Elements contributing to the transmission specific weight are listed below:

		PG-84	PHM
Reduction gear sp. wt.	W_{241}/SHP_I	1.36 lb/SHP	0.35 lb/SHP
Clutches, shafting, and propulsor sp. wt.	$W_{242-247}/SHP_I$	2.06 lb/SHP	0.77 lb/SHP

PHM's reduction gear is considerably lighter because it is coupled to a waterjet, which demands much less speed and torque than the controllable-pitch propellers employed by PG-84. The waterjet itself, with its supportive couplings, also has a considerably lower weight impact than the shafting and propellers required by PG-84.

The above analysis shows that the high performance specific ratios could be used in a displacement ship design, if waterjet propulsion is employed. By using the high performance ratios of 3.24 lb/SHP and 0.44 ft^3/SHP in PG-84, its main propulsion impact would be reduced by 22.6 tons and 5015 cubic feet. However, since there are differences in the propulsive coefficients and the specific fuel consumption rates, the fuel requirement would change. The fuel system impact would increase by 0.6 tons and 32 cubic feet.[1] The manning would be reduced, which would be beneficial in the ship's personnel area, decreasing both weight and volume there, also. Gas turbines and waterjets require low maintenance and provide good reliability. In general, the high performance criteria would provide a mobility subsystem that is lighter and more compact than its displacement counterpart, in spite of the slight increase in fuel demand.

If the hydrofoil's combined weight and volume of main propulsion machinery, propulsion fuel, and lift system are compared to the combined machinery and fuel weight and volume of a displacement ship designed to high performance standards and indices, an indication of calm water advantage can be made.

[1]Fuel changes can be determined by the following equations:

$$(W_F)_2 = \frac{SFC_2}{SFC_1} \times \frac{PC_1}{PC_2} \times (W_F)_1$$

$$(V_F)_2 = (W_F)_2/(W_F/V_F)_2$$

The powering estimate for a 231 ton displacement ship was taken from Grostick.[1] An effective horsepower (EHP) of 10,000 HP is estimated for a sustained speed of 40+ knots. Using the high performance propulsive coefficient of 0.53 and assuming a slight overage to be conservative, a value of 19,000 shaft horsepower is used for the displacement ship. A shaft horsepower margin (SHP_{MAR}) of 1.125 is employed.[9] The equations for main propulsion and fuel system weight and volume that were developed in Chapter 2 are used to produce the following results:

$$W_{FMP} + W_{MP} = 84.4 \text{ tons}$$

$$V_{FMP} + V_{MP} = 12{,}419 \text{ ft}^3$$

The corresponding values for the hydrofoil at the same speed are:

$$W_{FMP} + W_{MP} + W_{LFT} = 96.0 \text{ tons}$$

$$V_{FMP} + V_{MP} + V_{LFT} = 10{,}886 \text{ ft}^3$$

The mobility volume of the displacement ship is slightly higher due to the relatively low volume impact of a foil system, but the weight advantage of almost 12 tons,more than compensates for this. In calm water, where the advantage of

a foil system is not exercised, the employment of high performance design indices in a displacement ship results in a lower mobility impact than that attributed to the hydrofoil. Even though foils provide a higher lift-to-drag ratio at high speed than the planing hull, the weight of the foils could be converted to machinery in a redesign, and the resultant increase in shaft horsepower would provide more than enough power to drive the displacement ship at the same calm water speed as the hydrofoil. And, as noted above, the implementation of the hydrofoil's main propulsion design standards would provide additional weight reduction in the mobility area.

A main propulsion specific weight of 3.24 lb/SHP and a specific machinery volume of 0.44 ft^3/SHP will be used in the impact model for the redesign of PG-84.

3.2.1.2 - FFG-7 vs. HOC

The comparative results of FFG-7 and HOC are in general consistent with the high performance impact of the small ships, but a detailed side-by-side analysis would not be as meaningful, since there is a large disparity between the general characteristics of the ships. There are some differences that can be analyzed, however.

		FFG-7	HOC
Mobility wt. fr.	W_{MB}/Δ	26.1%	37.4%
Main prop. wt. fr.	W_{MP}/Δ	7.9%	5.3%
Fuel sys. wt. fr.	W_F/Δ	18.2%	32.1%
Mobility vol. fr.	V_{MB}/∇	18.9%	29.9%
Main prop. vol. fr.	V_{MP}/∇	12.4%	20.8%
Fuel sys. vol. fr.	V_F/∇	6.5%	9.1%

The main propulsion capacity-ship size ratio is over three times higher in HOC, which might indicate a high main propulsion weight fraction. Since the weight fraction is lower, the specific main propulsion weight must be checked to determine the reasons for the difference. The fuel fractions are both higher in HOC because of the hydrofoil's requirement to travel ~2500 miles at 40+ knots. This compares to ~2000 miles at 28+ knots achieved by FFG-7.

The following are the main propulsion specific ratios of the two large ships:

		FFG-7	HOC
Main prop. sp. wt.	W_{MP}/SHP_I	15.80 lb/SHP	3.24 lb/SHP
Main prop. sp. vol.	V_{MP}/SHP_I	1.60 ft^3/SHP	1.00 ft^3/SHP

FFG-7's weight impact is almost five times that of HOC. Further analysis is needed in this area. The main propulsion specific volume is smaller in HOC, due primarily to the

volume consciousness of the high performance design. The machinery box is more compact, and maximum use of the space is made.

Level 2

The main propulsion specific weight is influenced by several elements:

		FFG-7	HOC
Prime mover sp. wt.	W_{230}/SHP_I	3.49 lb/SHP	0.86 lb/SHP
Trans. sp. wt.	W_{240}/SHP_I	7.72 lb/SHP	1.58 lb/SHP
Supp. sp. wt.	$W_{250-260}/SHP_I$	2.61 lb/SHP	0.52 lb/SHP
Oper. fl. sp. wt.	W_{298}/SHP_I	0.84 lb/SHP	0.23 lb/SHP

The prime mover specific weight is considerably lower in HOC, even though LM 2500's are used in both ships. This is a result of two major factors. FFG-7's propulsion gas turbines are enclosed in sound-isolating modules, which account for almost 60% of the propulsion gas turbine weight group. HOC probably incorporates an unmanned engine room, precluding the necessity of these modules. FFG-7 also has an auxiliary propulsion unit which adds a considerable amount of weight to the main propulsion category and very little horsepower.

The transmission specific weight, support specific weight, and operating fluids specific weight are all lower in HOC. An investigation of the transmission area reveals that HOC

employs a planetary gear train instead of the more conventional locked-train reduction gear found in FFG-7. The shafting is considerably lighter in HOC also, probably due to shorter shafting runs and lightweight construction. The "calm-water" impact analysis was performed for the large ships also. A 1276 ton, Series 64 hull was taken from Grostick[1] to be used as the displacement ship. A speed of 40+ knots was estimated to require 30,183 EHP. The resulting shaft horsepower was computed to be 50,000 SHP. By applying a margin of 1.125 and using the equations developed in Chapter 2, the following results were obtained for the same speed and range:

DISPLACEMENT SHIP	HOC
$\frac{W_{MP} + W_{MPF}}{503.0 \text{ tons}}$	$\frac{W_{MP} + W_{MPF} + W_{LFT}}{712.5 \text{ tons}}$
$\frac{V_{MP} + V_{MPF}}{77{,}596 \text{ ft}^3}$	$\frac{V_{MP} + V_{MPF} + V_{LFT}}{70{,}058 \text{ ft}^3}$

As in the case of the small ships, the mobility volume of the displacement ship is higher, but the weight is dramatically lower, again indicating the attractiveness of applying high performance technology to displacement ship designs.

Since the level of detail is not great in the HOC design, and since several of the specific weights appeared to be unusually low, a main propulsion specific weight of 5 lb/SHP was chosen to be used in the FFG-7 redesign. This value is a

representative one and helps to eliminate any underestimation that may have been present in HOC's main propulsion analysis. The main propulsion specific volume of 1.00 ft^3/SHP can reasonably be used for FFG-7.

The application of these specific ratios to FFG-7 would result in reductions of 192.9 tons and 24,000 ft^3 in the main propulsion plant. Due to the difference in propulsive coefficient, however, an additional 26 tons and 1340 ft^3 would be required for fuel.

3.2.1.3 - Summary and Conclusions

The following observations and results can be obtained from the above analysis:

- The high performance ships are faster due to greater installed shaft horsepower per ton of displacement, and not because of significant superiority in the resistance characteristics.
- This horsepower advantage is achieved without an adverse weight and volume impact, because the specific ratios are considerably lower in spite of the fact that all four ships employ gas turbines. In the small ship, the primary reason is the incorporation of waterjet propulsion. Reasons for the lower impact in the large ships include compact design, lightweight shafting, planetary gears, and the absence of the heavy support modules that encase the displacement ship's prime movers.

- The high performance propulsive coefficients are lower, placing a larger demand on fuel than in the case of the displacement ships.
- In calm water, the displacement ship designed to high performance parameters and requirements can match the high performance ship in speed. Only in rough water does the advantage of a sustension system become apparent, as the displacement ship's performance is degraded considerably.
- The application of high performance design indices to a displacement ship results in an overall lower impact in the mobility area than the original ship demanded. However, due to the restrictive nature of the high performance parameters, the main propulsion operability may decrease.

3.2.2 - Hull Structure

Another area where there are significant differences in weight impact is that of hull structure. Table 10 lists the characteristics and design indices necessary for the comparative analysis.

3.2.2.1 - PG-84 vs. PHM

The structural weight fraction is considerably lower in PHM:

	PG-84	PHM
W_H/Δ	27.5%	23.9%

TABLE 10

HULL STRUCTURE CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_H/Δ	%	27.5	23.9	36.7	20.3
$W_{110-140}/\Delta$	%	20.4	12.9	26.5	--
W_{150}/Δ	%	3.2	1.8	3.1	1.8
$W_{160-170}/\Delta$	%	1.9	1.8	2.1	--
W_{180}/Δ	%	1.9	3.4	4.0	4.3
W_{198}/Δ	%	0	4.0	1.0	--
W_H/∇	lb/ft^3	3.07	2.71	5.73	2.55
$W_{110-140}/V_{BH}$	lb/ft^3	2.86	1.91	4.92	--
W_{150}/V_{SST}	lb/ft^3	1.77	.877	3.05	.739
$W_{160-170}/\nabla$	lb/ft^3	.218	.204	.323	--
$W_{180}/W_{200-700}$	lb/ton	83.72	150.2	223.6	222.7
Δ/∇	lb/ft^3	11.15	11.38	15.60	12.58
W_H	tons	66.57	55.18	1316.47	258.7
$W_{110-140}$	tons	49.45	29.77	949.90	--
W_{150}	tons	7.84	4.17	111.78	23.0
$W_{160-170}$	tons	4.74	4.15	74.23	--
W_{180}	tons	4.54	7.86	143.25	55.2
W_{198}	tons	0	9.23	37.31	--
$W_{200-700}$	tons	121.47	117.22	1435.2	555.2
V_{SST}	ft^3	9914	10649	82113	69686
V_{BH}	ft^3	38682	34895	432809	157412

NOTE: Names of design indices are included in Appendix B.

There can be several reasons for a difference in structural weight fraction between ships, including fabrication techniques and material selection. As in the case of any weight fraction, the functional allocation of another feature may influence the relative impact of the features analyzed. Vehicle density can also influence structural weight fraction. A volume limited, low density ship may have a high hull structure weight fraction.

PHM's structural specific weight is about 12% lower than PG-84's:

	PG-84	PHM
W_H/∇	3.07 lb/ft^3	2.71 lb/ft^3

This indicates that other functional areas are not driving the weight fraction down, and since the vehicle densities are nearly equal, a deeper analysis was conducted to determine PHM's lower impact. An investigation of the level 2 weight fractions and specific weights is needed:

		PG-84	PHM
Basic hull wt. fr.	$W_{110-140}/\Delta$	20.4%	12.9%
Superstructure wt.fr.	W_{150}/Δ	3.2%	1.8%
Sp. str. & masts wt.fr.	$W_{160-170}/\Delta$	1.9%	1.8%
Foundations wt.fr.	W_{180}/Δ	1.9%	3.4%

		PG-84	PHM
Free flooding liq. wt. fr.	W_{198}/Δ	0	4.0%
Basic hull sp. wt.	$W_{110-140}/V_{BH}$	2.86 lb/ft^3	1.91 lb/ft^3
Superstructure sp.wt.	W_{150}/V_{SST}	1.77 lb/ft^3	0.88 lb/ft^3
Sp. str. & masts sp. wt.	$W_{160-170}/V$	0.22 lb/ft^3	0.20 lb/ft^3
Foundations sp. wt.	$W_{180}/W_{200-700}$	83.72 lb/ton	150.20 lb/ton

The following conclusions and observations can be made:

- The significant differences in both weight fractions and specific weights occur in the areas of basic hull, superstructure, foundations, and free flooding liquids. Special structures, masts, and kingposts are comparable and need no further analysis.
- The reason for the difference in superstructure impact is that PG-84 employs a fibreglass composite in construction, while PHM's superstructure is all aluminum.
- Free flooding liquids account for 4% of PHM's full load displacement, because of large free flooding areas in the struts, bow thruster, and sea chest. Although water in a jet pump is considered part of the main propulsion plant, free flooding areas near the bellmouths and inlets are part of hull weight.
- Basic hull and superstructure specific weights use the appropriate enclosed volumes as their capacities. The foundation specific weight, however, is the ratio of

the foundation weight to the light ship weight less structural weight. This is a better indication of the impact made by foundations, since the weight of foundations is strongly influenced by the weights that are supported.

•There are four possible reasons for the lower basic hull specific weight found in PHM:

1) Different materials are used in construction
2) The hull girder is not designed to as great a factor of safety
3) Loads encountered are not as great
4) Construction techniques provide equal strength with less material

The first reason is ruled out since both hulls employ aluminum in construction. Both ships should be designed to equal factors of safety. As a matter of fact, the PHM foil system foundations apply the safety factors of 1.5 to yield strength, instead of ultimate strength, as in the case of most designs. The limiting load of a hydrofoil is met when slamming during broaching, and the displacement ship's limit results from bending. Although no structural analysis was conducted, these two loads are considered comparable, even though PHM's design standards appear to be more exacting in some areas.

The reasons for PHM's lower structural specific weight, then, are that more sophisticated construction and fabrication techniques are used. All-welded semimonoque construction is employed. Maximum use of integrally-extruded panels is made. Shell plating thickness varies with location along the hull; the least stressed areas have the thinnest plating.

- The principal reason for PHM's higher foundations specific weight is that it requires foil support foundations, which account for more than half of PHM's foundation weight. By eliminating the influence of the foil support foundations, the resultant foundations specific weight would be 131 lb/ton.[2]

PHM's specific ratios are lower in the areas of basic hull, superstructure, and special structures, masts and king-posts. By employing these values and the ones assigned to PG-84 in the other structural areas, the following hull structure specific weight is developed:

ITEM	PARAMETER	CAPACITY	WEIGHT(TONS)
Basic hull	1.91 lb/ft^3	38682 ft^3	32.98
Superstructure	0.88 lb/ft^3	9914 ft^3	3.89
Sp. str. & masts	0.20 lb/ft^3	48596 ft^3	4.34
Foundations	83.72 lb/ton	121.47 tons	4.54
			45.76 tons

[2]The equation used to determine this value is:

$$(W_{150}/W_{200-700})' = \frac{W_{150} - \text{foil supp. fdn. wt.}}{(W_{200-700}) - W_{567}}$$

$$W_H/\nabla = \frac{45.76}{48596} \times 2240 = 2.11 \text{ lb/ft}^3$$

If this value of hull structure specific weight is applied to PG-84, its structural weight would be reduced by 20.83 tons. This is a very significant impact, especially when considering that PG-84's entire payload weight is 29 tons.

The fabrication and construction techniques employed would be extremely expensive if the high performance standards were used, but since payload-carrying capacity and not acquisition cost is the selected figure of merit, the revised hull structure specific weight can be used in a displacement design. The weight reduction realized by using the value of 2.11 lb/ft^3 for the hull structure specific weight is very attractive, in spite of high initial cost and the possible increase in the vertical center of gravity.

3.2.2.2 - FFG-7 vs. HOC

HOC's hull structural impact is considerably lower than FFG-7's, in both weight fraction and specific weight. The following parameters are listed for analysis:

		FFG-7	HOC
Hull wt. fr.	W'_{BH}/Δ	29.6%	14.1%
Superstructure wt.fr.	W_{150}/Δ	3.1%	1.8%
Foundations wt.fr.	W_{180}/Δ	4.0%	4.3%
Hull sp. wt.	W'_{BH}/V_{BH}	5.49 lb/ft^3	2.57 lb/ft^3

		FFG-7	HOC
Superstructure sp. wt.	W_{150}/V_{SST}	3.05 lb/ft^3	0.74 lb/ft^3
Foundations sp. wt.	$W_{180}/W_{200-700}$	223.6 lb/ton	222.7 lb/ton

The detailed breakdown found in the small ships is not available for HOC, since it is only a conceptual design. This forces a more general definition of basic hull weight:

$$W'_{BH} = W_{100} - W_{150} - W_{180}$$

The following conclusions have been made from the above parameters:

- The hull specific weight is much lower in HOC, because the hull is constructed of aluminum, while steel is used in FFG-7.
- Although the superstructures of both ships are aluminum, HOC employs high performance construction and fabrication techniques, resulting in a much lower superstructure specific weight.
- The foundations specific weights are virtually equal for the two ships, in spite of HOC's foil support foundations which account for almost 50% of the total foundation weight. By eliminating the foil influence by the same method used in the small ships, the foundations specific weight is reduced to 208.2 lb/ton.

Using HOC's specific weights for superstructure and hull, and the adjusted foundation specific weight, a new hull structure specific weight was computed by the method used in the last section. The resultant hull structure specific weight was 2.86 lb/ft^3. If this value were applied to FFG-7, a reduction in the weight of hull structure of 659.7 tons would be realized. This is almost twice FFG's existing payload weight.

The construction of a 3600 ton aluminum hull would be extremely expensive and entail a considerable amount of technological risk. The 1276 ton displacement ship developed in the mobility analysis is an acceptable candidate for all-aluminum construction. Since the foil influence is removed, the lower foundations specific weight may be used in revising the hull structure specific weight, along with HOC's values of hull specific weight and superstructure specific weight. The resulting hull structure specific weight to be used in the design of a 1276 ton high performance displacement ship is 2.52 lb/ft^3.

3.2.2.3 - Summary and Conclusions

- The hull structure has a much lower impact on the high performance ships, due largely to sophisticated fabrication and construction techniques.
- The use of aluminum for hull construction is a great weight saver, as evidenced by the FFG-7 - HOC comparison.

- Foil support foundation weight is an important factor in the high performance ships.
- Although tremendous weight reduction can be attained with the application of high performance technology in the area of hull structure, the construction costs involved are correspondingly high; but if design philosophy mandates, considerable weight can be made available for payload.

3.2.3 - Personnel

Table 11 lists data and parameters that were used in comparing the personnel impact of the high performance and displacement ships. The high performance designs, employing efficient habitability standards, provide a lower ship impact than their displacement counterparts.

3.2.3.1 - PG-84 vs. PHM

The personnel weight and volume fractions are both lower in PHM:

	PG-84	PHM
W_M/Δ	6.1%	4.7%
V_M/∇	27.4%	22.6%

Both the crew size and the personnel capacity-ship size ratios are smaller in PHM, reasons which may drive the functional allocations down. Another reason might be the habitability standards used in the designs. The specific

TABLE 11

PERSONNEL CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_M/Δ	%	6.1	4.7	5.7	4.3
W_L/Δ	%	3.1	2.7	2.1	1.6
W_S/Δ	%	0.8	1.1	1.0	0.2
W_{MS}/Δ	%	2.2	0.9	2.6	2.5
V_M/∇	%	27.4	22.6	21.3	22.2
V_L/∇	%	22.5	19.0	13.6	16.7
V_S/∇	%	3.5	2.0	5.0	3.6
V_{MS}/∇	%	1.4	1.6	2.7	1.9
E_M/KW	%	7.7	5.3	--	--
M_M/M	%	13.9	4.8	19.3	--
W_M/M	tons/man	.618	.512	1.15	.64
W_L/M	lb/man	708.4	654.9	947.5	525.2
W_S/M	lb/man	179.2	260.3	443.9	69.5
W_{HAB}/M	lb/man	887.6	915.2	1391.4	594.7
W_{MS}/MxD	lb/man-day	35.53	33.22	26.52	27.81
V_M/M	ft^3/man	555.2	489.5	623.7	579.8
V_L/M	ft^3/man	455.0	412.6	398.1	437.0
V_S/M	ft^3/man	71.2	42.7	146.6	92.8
V_{HAB}/M	ft^3/man	526.2	455.3	544.7	529.8
$V_{2.21}/M$	ft^3/man	26.7	0.0	7.39	0.0
$V_{2.22}/M$	ft^3/man	42.3	34.2	42.90	37.95
$V_{2.23}/M$	ft^3/man	0.0	0.0	16.07	22.09
$V_{2.24}/M$	ft^3/man	2.1	5.4	42.45	15.17
$V_{2.25}/M$	ft^3/man	0.0	0.0	37.75	10.16

Item	Units	PG-84	PHM	FFG-7	HOC
V_{MS}/MxD	ft^3/man-day	2.08	4.89	1.75	1.67
E_M/M	KW/man	.638	1.005	--	--
W_M/V_M	lb/ft^3	2.49	2.34	4.14	2.46
M/Δ	$\frac{\text{men}}{\text{100 tons}}$	11.17	9.04	4.91	6.82
W_M	tons	14.84	10.76	203.1	55.5
W_L	tons	7.59	6.14	74.45	20.4
W_S	tons	1.92	2.44	34.88	2.7
W_{MS}	tons	5.33	2.18	93.77	32.4
V_M	ft^3	13324.7	10279	109763	50443
V_L	ft^3	10919.7	8664	70073	38018
V_S	ft^3	1707.8	897	25793	8072
$V_{2.21}$	ft^3	641.5	0.0	1300	0.0
$V_{2.22}$	ft^3	1016.3	718	7550	3302
$V_{2.23}$	ft^3	0.0	0.0	2828	1922
$V_{2.24}$	ft^3	50.0	114	7471	1320
$V_{2.25}$	ft^3	0.0	0	6644	884
V_{MS}	ft^3	697.3	718	13897	4353
E_M	KW	15.32	21.1	--	--
M	men	24	21	176	87
M_S	men	3	1	34	--
D	days	14	7	45	30

NOTE: Names of design indices are included in Appendix B.

ratios are better indications of the reasons for the lower impact in PHM.

		PG-84	PHM
Pers. sp. wt.	W_M/M	.62 tons/man	.51 tons/man
Pers. sp. vol.	V_M/M	555.2 ft^3/man	489.5 ft^3/man

The specific volume displays the more compact habitability associated with the high performance design, allotting 88% of the personnel volume per man provided to PG-84. The personnel specific weight is also lower in PHM. Reasons for this include the shorter stores endurance period which will be discussed in the level 2 analysis.

The personnel energy parameters discussed are derived from the cruise condition, since most personnel loads are stripped during battle. The personnel energy fraction is lower for PHM, but its specific energy is higher. This is due primarily to the fact that there is a 9 KW hot water heater included in PHM's load analysis, and no heater is listed for PG-84. If this amount is added to the PG-84's personnel energy total, the resultant specific energy is equal to PHM's.

The area of manning is one in which the hydrofoil has a decidedly lower impact, where PHM uses only one man for personnel support compared to the three employed by PG-84. This reduction is due to the fact that PHM employs more versatility in its crew, not requiring dedicated billets for personnel support with the exception of a cook.

Level 2

Below is a more detailed listing of the personnel specific ratios:

		PG-84	PHM
Living sp.wt.	W_L/M	708.4 lb/man	654.9 lb/man
Support sp.wt.	W_S/M	179.2 lb/man	260.3 lb/man
Pers. st.sp.wt.	$W_{MS}/(MxD)$	35.53 $\frac{lb}{man\text{-}day}$	33.22 $\frac{lb}{man\text{-}day}$
Living sp.vol.	V_L/M	455.0 ft^3/man	412.6 ft^3/man
Support sp.vol.	V_S/M	71.2 ft^3/man	42.7 ft^3/man
Pers. st.sp.vol.	$V_{MS}/(MxD)$	2.08 $\frac{ft^3}{man\text{-}day}$	4.89 $\frac{ft^3}{man\text{-}day}$

Both the living specific weight and volume are lower in PHM, due to the more restrictive design standards. The support specific volume is much smaller in PHM, but the support specific weight is higher. This is due to the volume premium assigned to PHM's design and will be discussed in more detail in the level 3 analysis.

The personnel stowage specific weights are comparable, which should be expected. PHM's specific volume is more than twice as large as PG-84's, indicating that the limited stores period (7 days) could be increased considerably without an adverse volume impact. It should be noted here that PHM's support specific weight would be considerably higher if it were not for the fact that her distilling plant is larger and, as will be pointed out in the auxiliaries analysis, heavier. PHM carries less than one ton of potable water while PG-84 provides three times that amount.

Level 3

The personnel support specific volume is analyzed further:

		PG-84	PHM
Ship's office sp.vol.	$V_{2.21}/M$	26.7 ft^3/man	0
Galley sp. vol.	$V_{2.22}/M$	42.3 ft^3/man	34.2 ft^3/man

PHM does not have a ship's office,and its galley is 30% smaller than PG-84's. This is but another indication of the compactness and necessity of volume reduction in a high performance design.

The application of the high performance specific ratios for living weight and volume, personnel stowage weight, and support volume can be made to PG-84. A reduction of 0.92 tons and 1701.6 ft^3 in the personnel area would result. Although the weight reduction is less than a ton, the volume reduction is significant, since it also influences the weights of hull structure, auxiliaries, ship systems and other ship operations. PHM's crew size can also be applied to PG-84 and when coupled with the other high performance standards, the total reduction would be 2.66 tons and 3151.9 ft^3.

The reduction in crew size would result in fewer men available to handle battle damage and conduct casuality control procedures. The high performance personnel standards would restrict habitability somewhat, but acceptable standards would still be met. The following specific ratios can be applied to PG-84:

Hab. sp. wt.	$W_{HAB}/M = 834.1$ lb/man
Pers. stow. sp. wt.	$W_{MS}/(M \times D) = 33.22$ lb/man-day
Hab. sp. vol.	$V_{HAB}/M = 455.3\ ft^3/man$
Pers. stow. sp. vol.	$V_{MS}/(M \times D) = 2.08\ ft^3/man\text{-}day$

3.2.3.2 - FFG-7 vs. HOC

The personnel weight and volume fractions for the large ships are given below.

	FFG-7	HOC
W_M/Δ	5.7%	4.3%
V_M/∇	21.3%	22.2%

HOC's weight fraction is lower because it has a smaller crew and a shorter endurance period. Its volume fraction is higher than FFG-7's, however, because its capacity-ship size ratio is higher, indicating a relatively larger crew.

Consider the specific ratios:

		FFG-7	HOC
Pers. sp. wt.	W_M/M	1.15 ton/man	0.64 ton/man
Pers. sp. vol.	V_M/M	623.7 ft^3/man	579.8 ft^3/man

Both the specific weight and volume are lower in HOC. This again reflects the efficient use of habitability weight and volume in the high performance design. The larger personnel capacity-ship size ratio for HOC indicates a denser

manning level than FFG-7, but the high performance specific volume counters this influence and actually results in a lower ship impact for HOC.

Further analysis is conducted to determine reasons for the differences in the specific ratios:

		FFG-7	HOC
Living sp.wt.	W_L/M	947.5 lb/man	525.2 lb/man
Support sp.wt.	W_S/M	443.9 lb/man	69.5 lb/man
Pers. st.sp.wt.	$W_{MS}/(M \times D)$	26.52 $\frac{\text{lb}}{\text{man-day}}$	27.81 $\frac{\text{lb}}{\text{man-day}}$
Living sp.vol.	V_L/M	398.1 ft^3/man	437.0 ft^3/man
Support sp.vol.	V_S/M	146.6 ft^3/man	92.8 ft^3/man
Pers. st.sp.vol.	$V_{MS}/(M \times D)$	1.75 $\frac{\text{ft}^3}{\text{man-day}}$	1.67 $\frac{\text{ft}^3}{\text{man-day}}$

The personnel stowage specific weights and volumes of the two ships are comparable. The areas of living and support, however, have appreciable differences. HOC's living specific weight is lower, indicating more restrictive habitability. The support specific weight, however, is only about one-sixth that of FFG-7's. This great difference is probably due to the cursory level of detail attained in HOC's design and does not appear to be reasonable. FFG-7's support specific weight is the highest of all the ships analyzed, due to an overage of habitability, but even with the large value associated with FFG-7, the difference is still too great. For purposes of this analysis a nominal value of 300 lb/man will be used in the impact study.

The living specific volume is about 10% higher for HOC. A better indication of the high performance impact may be made by comparing the overall habitability specific volume:

	FFG-7	HOC
V_{HAB}/M	544.7 ft^3/man	529.8 ft^3/man

This more general parameter helps reduce the anomalies that may be present in the conceptual design of HOC and gives a better indication of the volume-conscious high performance design. The habitability specific volume is lower in HOC in spite of the fact that it allots a greater volume per man in the living area. This is because of the support specific volume, which is only 63% that of FFG-7's. A detailed breakdown of support specific volume shows why:

		FFG-7	HOC
Admin. sp.vol.	$V_{2.21}/M$	7.39 ft^3/man	0 ft^3/man
Food prep.sp.vol.	$V_{2.22}/M$	42.90 ft^3/man	37.95 ft^3/man
Med.&dent.sp.vol.	$V_{2.23}/M$	16.07 ft^3/man	22.09 ft^3/man
Pers.Svcs.sp.vol.	$V_{2.24}/M$	42.45 ft^3/man	15.17 ft^3/man
Rec.&wel.sp.vol.	$V_{2.25}/M$	37.75 ft^3/man	10.16 ft^3/man

In all areas of support, HOC uses less volume per man, except for medical and dental, which is not significant. The largest difference is in the recreation and welfare area,

where FFG-7 has almost four times the specific volume of HOC. This is one area where the high performance standard of compactness in habitability is extremely apparent. When volume is at a premium, non-militarily-essential areas are reduced considerably. Again, as in the case of PHM, no administration volume has been assigned to the high performance ship. This may be a reason for the greater living specific volume, since berthing areas may serve as offices also.

It is concluded that the high performance specific volumes can be applied to FFG-7. The living specific weight and a modified support specific weight can also be used, resulting in a habitability specific weight of 825.2 lb/man. Using these parameters results in a reduction of 44.5 tons and 3256 ft^3 in the personnel functional category of FFG-7. Since a manning document has not been detailed for HOC, a crew reduction in FFG-7 would be presumptous.

The only adverse impact imposed by the application of the high performance parameters is the resultant decrease in habitability standards. Since they still represent an acceptable level, though, the cost is slight when compared to the weight and volume made available to the payload designer.

3.2.3.3 - Summary and Conclusions

- High performance ships use less space and weight for personnel than displacement ships. This is necessary because of the design sensitivity of high performance ships to excessive weight.

- The high performance habitability standards can be applied to displacement ships, and their employment results in an appreciable decrease in personnel weight and volume.
- A reduction in crew size provides additional savings in weight and volume requirements, and when coupled with the applicable high performance standards, a considerably lower impact is realized.

3.2.4 - Electric Plant

Several major differences in the electric plants of the ships result in lower impacts for the hydrofoils. Table 12 lists the data necessary for the analysis.

3.2.4.1 - PG-84 vs. PHM

The electric plant weight and volume fractions for the small ships are presented below:

	PG-84	PHM
W_E/Δ	2.6%	2.3%
V_E/∇	5.7%	5.4%

At first, it does not appear that the high performance impact has much influence in the electric plant, but an investigation of the electric plant capacity-ship size ratio and the specific ratios indicates otherwise:

TABLE 12

ELECTRIC PLANT CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_E/Δ	%	2.6	2.3	4.8	2.7
V_E/∇	%	5.7	5.4	4.7	3.3
E_E/KW	%	1.2	2.9	--	--
M_E/M	%	8.3	4.8	4.0	--
W_E/KW	lb/KW	69.22	30.35	97.12	51.82
W_{310}/KW	lb/KW	58.91	22.74	52.05	37.78
W_{324}/KW	lb/KW	7.73	7.22	10.48	6.12
W_{340}/KW	lb/KW	0.0	0.0	22.41	--
W_{398}/KW	lb/KW	2.56	0.39	5.42	7.92
W_{475}/KW	lb/KW	0.0	0.0	6.76	0.0
V_E/KW	ft^3/KW	13.75	6.20	6.04	5.07
W_F/V_F	lb/ft^3	39.73	33.08	43.84	44.25
KW/Δ	KW/ton	.83	1.72	1.12	1.18
W_E	tons	6.18	5.42	173.43	34.7
W_{310}	tons	5.26	4.06	92.95	25.3
W_{324}	tons	.69	1.29	18.71	4.1
W_{340}	tons	0.0	0.0	40.02	--
W_{398}	tons	.23	.07	9.68	5.3
W_{475}	tons	0.0	0.0	12.07	0.0
V_E	ft^3	2750.6	2479	24143	7600
M_E	men	2	1	7	--
E_E	KW	2.39	11.14	--	--
KW	KW	200	400	4000	1500
SFCA	lb/HP-hr	.50 [1]	.85 [10]	.44 [8]	.82 [4]

Item	Units	PG-84	PHM	FFG-7	HOC
R	n.m.	500(est)	700(est)	2000(est)	2500(est)
V	knots	~40	40+	28+	40+
TLPE	--	.95	.95	.95	.95

NOTE: Names of design indices are included in Appendix B

	PG-84	PHM
KW/Δ	.83 KW/ton	1.72 KW/ton
W_E/KW	69.22 lb/KW	30.35 lb/KW
V_E/KW	13.75 ft^3/KW	6.20 ft^3/KW

Several interesting observations can be made:

- PHM's capacity-ship size ratio is twice that of PG-84's, but the weight and volume fractions are both lower. This fact is reflected in PHM's specific ratios, which are both more than a factor of two lower than PG-84's.
- The main reasons for the lower specific ratios attributed to PHM are that the prime movers are gas turbines, and their generators produce 400 HZ electrical power, thereby eliminating the requirement for a large amount of conversion equipment. A more detailed analysis of the electric plant differences is presented in the level 2 discussion.
- The electric plant manning fraction is lower in PHM, due to the reduction in maintenance requirements and machinery operation of the gas turbine/400 HZ generators.

Level 2

In order to identify more specifically the elements of the electric plant that contribute to the lower impact associated with the hydrofoil, a further breakdown of the specific weights is required:

		PG-84	PHM
Power gen. sp.wt.	W_{310}/KW	58.91 lb/KW	22.74 lb/KW
Switchgear sp.wt.	W_{324}/KW	7.73 lb/KW	7.22 lb/KW
Oper. fl. sp.wt.	W_{398}/KW	2.56 lb/KW	0.39 lb/KW

The major differences are the areas of electric power generation and operating fluids. PHM's switchgear specific weight is slightly lower also. This is because the weight of switchgear is dominated by its modular structural framing and mounting. The addition of electrical capacity does not strongly influence the size and bulk of switchgear and panels, and consequently the specific weight will decrease as the capacity increases.

The largest difference in the electric plant, however, is in the power generation area. PHM employs gas turbine prime movers and 400 HZ generators, whereas PG-84 has a Diesel/60 HZ system.

It is concluded that the high performance specific ratios can be used in PG-84. An electric plant specific weight of 30.35 lb/KW and a specific volume of 6.20 ft^3/KW would reduce the electrical impact by 3.47 tons and 1510 ft^3 in PG-84. As in the case of main propulsion, however, the high performance system has a greater demand on fuel, and this must be taken into account.

The combined weights and volumes of the electric plant and the fuel required for endurance at the hydrofoil's design standards were computed and compared:

	PG-84	Redesigned PG-84
$W_E + W_{FE}$	7.23 tons	4.49 tons
$V_E + V_{FE}$	2809.1 ft^3	1340.4 ft^3

In spite of the increased fuel consumption, the total electric plant impact is still considerably lower in both weight and volume when the high performance design indices are used. Initial cost may be higher since 400 HZ motors and other equipment may not be considered standard acquisition items, but the overall weight and volume savings that are realized result in the selection of the electric plant specific ratios of 30.35 lb/KW and 6.20 ft^3/KW for redesign of the PG-84.

3.2.4.2 - FFG-7 vs. HOC

Both the weight and volume fractions are lower in HOC. Since HOC's capacity-ship size ratio is larger, implying a higher electrical capacity per ton displacement, the specific ratios are analyzed:

		FFG-7	HOC
Elec. plant sp.wt.	W_E/KW	97.12 lb/KW	51.82 lb/KW
Elec. plant sp.vol.	V_E/KW	6.04 ft^3/KW	5.07 ft^3/KW
Prime mover sp.wt.	W_{310}/KW	52.05	37.78
Switchgear sp.wt.	W_{324}/KW	10.48	6.12

		FFG-7	HOC
Elec supp. sp.wt.	W_{340}/KW	22.41	0
Oper. fl. sp.wt.	W_{398}/KW	5.42	7.92
Degaussing sp.wt.	W_{475}/KW	6.76	0
	$W_{310} + W_{340} + W_{398}/KW$	79.88 lb/KW	45.70 lb/KW

The following observations and conclusions were made:

- The level of detail of the HOC design does not include weight for power generation support. This may have been included in the prime mover figure. To eliminate some of the uncertainty, the specific weights of power generation, support, and operating fluids were combined.
- This combined specific ratio is considerably lower in HOC, because it employs gas turbines for the electric plant prime movers. FFG-7's generators are powered by diesel engines.
- The degaussing specific weight is zero for HOC because of its aluminum hull. If FFG-7 were redesigned with an aluminum hull, over 12 tons would be saved in degaussing equipment.
- The electric plant specific volume is lower in HOC because of the attention to the premium placed on volume in a high performance design.

The high performance specific ratios can be applied to FFG-7, with the exception of degaussing, unless the redesign includes an aluminum hull. Assuming, however, that the high

performance design indices are used in other functional categories as well, the FFG-7's electric plant can be redesigned to 51.82 lb/KW and 5.07 ft^3/KW. This would result in a reduction of 80.89 tons and 3880 ft^3.

As in the case of the small ships, though, the high performance standards carry with them an increase in fuel consumption. A similar fuel analysis was performed for FFG-7, at high speed.

	FFG-7	Redesigned FFG-7
$W_E + W_{FE}$	232.54 tons	202.69 tons
$V_E + V_{FE}$	27152.2 ft^3	25856.1 ft^3

The electric plant weight and volume reduction overrides the additional fuel demand, resulting in a lower overall ship impact required for power generation.

3.2.4.3 - Summary and Conclusions

- The high performance electric plants are considerably lighter and provide a much lower ship impact than the displacement ship plants because of the incorporation of gas turbine prime movers.
- The low gas turbine impact is reduced somewhat because of a higher fuel demand than a Diesel prime mover.
- The overall ship impact of power generation is still lower if the high performance standards are used, because of the large advantage gained in machinery weight reduction.

3.2.5 - Auxiliaries

The characteristics and parameters required for the auxiliaries analysis are presented in Table 13. Some of the weights are marked with a prime ('). This indicates that the weight includes only those elements of the group that are listed in the auxiliaries weight breakdown, e.g., $W'_{510} = .5W_{512} + .5W_{514} + W_{516} + W_{517}$.

3.2.5.1 - PG-84 vs. PHM

The auxiliaries weight and volume fractions are both higher in PHM:

	PG-84	PHM
W_A/Δ	3.7%	4.5%
V_A/∇	8.5%	14.1%

Since many of the auxiliaries deal with whole ship functions (heating, air conditioning), it may be expected that the ship with the smaller vehicle density (higher relative enclosed volume) would have the dominant auxiliary impact. Since they are comparable for the two ships, however, an investigation of the specific ratios is needed:

		PG-84	PHM
Auxiliaries sp.wt.	W_A/∇	.407 lb/ft^3	.515 lb/ft^3
Auxiliaries sp.vol.	V_A/∇	.085 ft^3/ft^3	.141 ft^3/ft^3
Climate control sp. wt.	W'_{510}/∇	.051 lb/ft^3	.080 lb/ft^3
Sea wat.sys.sp.wt.	W'_{520}/∇	.014 lb/ft^3	0

TABLE 13

AUXILIARIES CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_A/Δ	%	3.7	4.5	6.9	1.3
V_A/∇	%	8.5	14.1	12.3	2.9
E_A/KW	%	24.8	23.8	--	--
M_A/M	%	8.3	9.5	5.1	--
W_A/∇	lb/ft^3	.407	.515	1.071	.167
$W_{510'}/\nabla$	lb/ft^3	.051	.080	.208	.021
$W_{520'}/\nabla$	lb/ft^3	.014	0.0	.048	.011
$W_{530'}/M$	lb/man	37.33	142.93	78.4	0.0
$W_{550'}/\nabla$	lb/ft^3	.009	.112	.086	.095
$W_{560'}/\Delta$	lb/ton	39.45	9.01	42.97	0.0
$W_{570-580'}/\Delta$	lb/ton	15.37	41.83	39.48	7.02
$W_{590'}/\nabla$	lb/ft^3	.042	0.0	12.92	0.0
V_A/∇	ft^3/ft^3	.085	.141	.123	.029
∇/Δ	ft^3/ton	200.93	196.89	143.62	177.99
W_A	tons	8.83	10.48	246.14	16.9
$W_{510'}$	tons	1.11	1.63	47.70	2.1
$W_{520'}$	tons	.30	0.0	10.92	1.12
$W_{530'}$	tons	.40	1.34	6.16	0.0
$W_{550'}$	tons	.20	2.27	19.70	9.68
$W_{560'}$	tons	4.26	.93	68.78	0.0
$W_{570-580'}$	tons	1.66	4.32	63.20	4.0
$W_{590'}$	tons	.90	0.0	29.69	0.0

Item	Units	PG-84	PHM	FFG-7	HOC
V_A	ft^3	4112.5	6412	63407	6605
E_A	KW	47.65	99.3	--	--
M_A	men	2	2	9	--

NOTE: Names of design indices are included in Appendix B.

		PG-84	PHM
Dist. plant sp.wt.	W'_{530}/M	37.33 lb/man	142.93 lb/man
Air gas & hyd.sys. sp.wt.	W'_{550}/∇	.009 lb/ft^3	.112 lb/ft^3
Steer. & maneuv. sp.wt.	W'_{560}/Δ	39.45 lb/ton	9.01 lb/ton
Deck aux. sp.wt.	$W'_{570-580}/\Delta$	15.37 lb/ton	41.83 lb/ton
Oper. fl. sp.wt.	W'_{590}/∇	.042 lb/ft^3	0

The following observations were made concerning the auxiliaries:

- Since the distilling plant is dedicated to potable water, the appropriate capacity is crew size. Steering and maneuvering capacities are linked with ship displacement more strongly than volume, so displacement is used as the capacity. The same holds true in the case of deck auxiliaries.
- The distilling plant specific weight is higher in PHM. As mentioned in the personnel section, this is due to the fact that PHM has a lower potable water stowage capacity, and a larger distilling plant is necessary.
- The air, gas, and hydraulic systems and deck auxiliaries specific weights are higher in PHM. This can be traced to foil support functions such as locks, actuators, and foil-handling equipment.
- The steering and maneuvering specific weight is four times lower in PHM. This results from PHM's use of directed waterjets for maneuvering instead of the

conventional steering gear and rudders. If waterjet propulsion were used in PG-84, the ship impact would be lowered in the area of auxiliaries also.

In a redesign of PG-84, modified specific ratios are used. Since an advantage can be gained from the use of the high performance steering and maneuvering weight, it is incorporated in the revised specific weight.

ITEM	PARAMETER	CAPACITY	WEIGHT (TONS)
Climate control	.051 lb/ft^3	48596 ft^3	1.11
Sea water systems	.014 lb/ft^3	48596 ft^3	.30
Dist. plant	37.33 lb/man	24 men	.40
Air, gas & hyd. sys.	.009 lb/ft^3	48596 ft^3	.20
Steering & maneuv.	39.45 lb/ton	241.86 tons	.97
Deck aux.	15.37 lb/ton	241.86 tons	1.66
Oper. fluids	.041 lb/ft^3	48596 ft^3	.90
			5.54 tons

$$W_A/\nabla = \frac{5.54}{48596} \times 2240 = 0.255 \text{ lb/ft}^3$$

PG-84's auxiliaries specific volume of .085 ft^3/ft^3 is used in the redesign since the high performance specific volume would not result in a lower ship impact. The application of the modified specific weight would result in a reduction of PG-84's auxiliary weight by 3.3 tons. There would be no reduction in volume.

If waterjet propulsion is used in PG-84, the corresponding steering and maneuvering system can be used also, providing additional weight saving, and no increase in maintenance requirements or technological risk.

3.2.5.2 - FFG-7 vs. HOC

Unlike the small ships, FFG-7's weight and volume fractions are higher than the high performance ship's, but the vehicle density is also higher. The specific ratios provide reasons for this:

Aux. sp.wt.	W_A/∇	1.071 lb/ft^3	.167 lb/ft^3
Aux. sp.vol.	V_A/∇	.123 ft^3/ft^3	.029 ft^3/ft^3
Climate cont. sp.wt.	W'_{510}/∇	.208 lb/ft^3	.021 lb/ft^3
Sea water sys. sp.wt.	W'_{520}/∇	.048 lb/ft^3	.011 lb/ft^3
Dist. plant sp.wt.	W'_{530}/M	78.4 lb/man	0
Air, gas & hyd. sp.wt.	W'_{550}/∇	.086 lb/ft^3	.095 lb/ft^3
Steer & main sp.wt.	W'_{560}/Δ	42.97 lb/ton	0
Deck aux. sp.wt.	$W'_{570-580}/\Delta$	39.48 lb/ton	7.02 lb/ton
Oper. fl.sp.wt.	W'_{590}/∇	12.92 lb/ft^3	0

There are several important observations that were made concerning the above parameters:

- The air, gas, and hydraulic specific weight in HOC is higher because of the foil system influence.
- All the other specific weights are much lower, or non-existant for HOC. Further investigation revealed that, in the case of steering and maneuvering, no weight at all was assigned to the auxiliaries weight group.
- Operating fluids may have been incorporated in another weight group.
- Although HOC's design included a distilling plant, no weight was assigned.

Because of this lack of detail in the HOC design, a confident assessment of the applicability or feasibility of the high performance technology cannot be made. In order to provide an input to the impact study, FFG-7's specific ratios are reduced in proportion to that obtained for the small ships. This represents a 37% reduction in the specific weight and no specific volume reduction. The resultant parameters to be used in a redesign are .672 lb/ft^3 for auxiliaries specific weight and .123 ft^3/ft^3 for auxiliaries specific volume.

The auxiliaries impact would be reduced by 91.72 tons if the modified specific weight is applied to FFG-7. There would be no reduction in volume.

3.2.5.3 - Summary and Conclusions

- The impact of high performance technology is apparent. The additional equipment needed for foil support is considerable, but its impact can be reduced in other auxiliary areas.

- In the small ships, the foil support influence is reduced by the steering and maneuvering system employed by PHM.
- The large ship study is not as conclusive, but by applying the general high performance philosophy of weight consciousness, the auxiliary weight allocation can be reduced in a displacement ship.
- The application of high performance design indices does not reduce the operability of the auxiliary plant, because the specific volume remains the same and the specific weight is reduced by the use of lighter weight systems with equal reliability and maintainability.

3.2.6 - Other Ship Operations

Table 14 includes all important parameters and characteristics used in the other ship operations comparison. This functional category includes ship control, maintenance, and tankage.

3.2.6.1 - PG-84 vs. PHM

PHM has a lower weight fraction, but a higher volume fraction than PG-84 in other ship operations; this is the result of the specific ratios, which are broken down further:

		PG-84	PHM
Other ship ops sp.wt.	W_{OSO}/∇	.401 lb/ft^3	.164 lb/ft^3
Control sp.wt.	W_C/∇	.110 lb/ft^3	.140 lb/ft^3

TABLE 14

OTHER SHIP OPERATIONS CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_{OSO}/Δ	%	3.6	1.4	2.2	0.9
V_{OSO}/∇	%	6.9	13.6	11.8	9.6
W_{OSO}/∇	lb/ft^3	.401	.164	.349	.114
W_C/∇	lb/ft^3	.110	.140	.160	.071
W_{MN}/∇	lb/ft^3	.267	.024	.144	.040
W_T/∇	lb/ft^3	.024	--	.045	.003
V_{OSO}/∇	ft^3/ft^3	.069	.136	.118	.096
V_C/∇	ft^3/ft^3	.023	.030	.039	.053
V_{MN}/∇	ft^3/ft^3	.043	.021	.028	.033
V_T/∇	ft^3/ft^3	.004	.084	.051	.010
W_{OSO}	tons	8.70	3.33	80.17	11.6
W_C	tons	2.38	2.84	36.75	7.2
W_{MN}	tons	5.80	.49	33.19	4.1
W_T	tons	.52	--	10.23	0.3
V_{OSO}	ft^3	3373.8	6176	60661	21756
V_C	ft^3	1117.3	1367	20208	12114
V_{MN}	ft^3	2071.5	976	14375	7451
V_T	ft^3	185.0	3833	26078	2191

NOTE: Names of design indices are included in Appendix B.

		PG-84	PHM
Maint. sp.wt.	W_{MN}/∇	.267 lb/ft^3	.024 lb/ft^3
Tankage st.wt.	W_T/∇	.024 lb/ft^3	0 lb/ft^3
Other ship ops. sp.vol.	V_{OSO}/∇	.069 ft^3/ft^3	.136 ft^3/ft^3
Control sp.vol.	V_C/∇	.023 ft^3/ft^3	.030 ft^3/ft^3
Maint. sp.vol.	V_{MN}/∇	.043 ft^3/ft^3	.021 ft^3/ft^3
Tankage sp.vol.	V_T/∇	.004 ft^3/ft^3	.084 ft^3/ft^3

The following conclusions were drawn:

- The maintenance specific weight is higher in PG-84 because of its maintenance philosophy, which demands more on-board repair of equipment and machinery. PG-84's maintenance specific volume is correspondingly higher.
- The tankage specific volume is much greater for PHM, due to its large number of voids. This implies that PHM is weight limited, which is expected for a hydrofoil, since takeoff weight is critical, and yet adequate supportive volume is required for hullborne operations.
- The other specific ratios do not display radical differences, and overall ship impact would not be affected measurably by these changes.

If the high performance maintenance standards were applied to PG-84, the following specific ratios would result:

$$W_{OSO}/\nabla = .158 \text{ lb/ft}^3$$

$$V_{OSO}/\nabla = .048 \text{ ft}^3/\text{ft}^3$$

The use of these modified parameters would result in a lower ship impact of 5.27 tons and 1020.5 ft^3 in the functional category of other ship operations. Maintainability may decrease slightly, but if this high performance design feature is coupled with those of other functional areas, the overall reliability of the displacement ship would be equal to the hydrofoil's. Reduction in maintainability implies the use of more reliable equipment, which would be provided by the other high performance features.

3.2.6.2 - FFG-7 vs. HOC

The other ship operations weight and volume fractions are both lower in HOC, driven by the lower specific ratios that are attained. An investigation at the next level of detail was required:

		FFG-7	HOC
Control sp.wt.	W_C/∇	.160 lb/ft^3	.071 lb/ft^3
Maint. sp.wt.	W_{MN}/∇	.144 lb/ft^3	.040 lb.ft^3
Tankage sp.wt.	W_T/∇	.045 lb/ft^3	.003 lb/ft^3
Control sp.vol.	V_C/∇	.039 ft^3/ft^3	.053 ft^3/ft^3
Maint. sp.vol.	V_{MN}/∇	.028 ft^3/ft^3	.033 ft^3/ft^3
Tankage sp.vol.	V_T/∇	.051 ft^3/ft^3	.010 ft^3/ft^3

The following observations were made relating to the differences in the specific ratios:

- The tankage specific ratios are considerably higher in FFG-7. This is the result of an extensive clean ballast system employed in the displacement ship and not present in the hydrofoil.

- In the areas of maintenance and control, the specific weights are lower in HOC, but the specific volumes are slightly higher. Reasons for this may include lower maintenance requirements and lighter weight control systems in the hydrofoil.

The high performance specific weight can be applied to FFG-7 in addition to HOC's specific tankage volume. This would reduce the maintainability slightly and eliminate the clean ballast system, but the resultant weight and volume savings would be significant. By applying a specific weight of .114 lb/ft^3 and a specific volume of .077 ft^3/ft^3 to FFG-7, a reduction of 54.0 tons and 21,111.8 ft^3 would occur in the functional area of other ship operations.

3.2.6.3 - Summary and Conclusions

- The two areas of other ship operations that contribute significantly to this functional category are maintenance and tankage.
- The maintenance philosophies of the high performance ships allow for a reduction in weight and volume in this area. When applied to a displacement ship, the maintenance operability may decrease, unless coupled with high performance technology in other functional areas.
- The use of the large hydrofoil's tankage specific volume would drastically reduce volume impact in FFG-7 by removing the clean ballast system. Although quite attractive

from a designer's standpoint, ecological considerations may have to be dealt with.

3.2.7 - Ship Systems

Table 15 is provided to list the characteristics and design indices used in the comparison of the ship systems category.

3.2.7.1 - PG-84 vs. PHM

PHM's ship systems weight and volume fractions are both lower than their counterparts in PG-84. The specific ratios are also lower, indicating the lower ship impact.

		PG-84	PHM
Ship systems sp.wt.	W_{SS}/∇	1.089 lb/ft^3	.837 lb/ft^3
Ship systems sp.vol.	V_{SS}/∇	.074 ft^3/ft^3	.023 ft^3/ft^3

- PHM's specific weight may be lower due to conscientious attention to weight reduction in the efficient routing of cable runs, piping, and ventilation ducting. There is less non-structural compartmentation in the hydrofoil, which contributes to this low value, in addition to the general weight consciousness applied throughout the high performance design.
- The ship systems specific weight also reflects PHM's low specific ratios in auxiliaries and hull, which are sources of much of the ship systems weights.

TABLE 15

SHIP SYSTEMS CHARACTERISTICS AND DESIGN INDICES

Item	Units	PG-84	PHM	FFG-7	HOC
W_{SS}/Δ	%	9.8	7.4	8.3	3.7
V_{SS}/∇	%	7.4	2.3	12.0	5.7
W_{SS}/∇	lb/ft^3	1.089	.837	1.290	.465
V_{SS}/∇	ft^3/ft^3	.074	.023	.120	.057
W_{SS}	tons	23.62	17.01	296.59	47.1
V_{SS}	ft^3	3578	1035	61899	12891

NOTE: Names of design indices are included in Appendix B.

- The ship systems specific volume is lower in PHM because of the incorporation of narrow passageways and limited access. This provides another good indication of the compactness of the high performance design and its sensitivity to excess volume.

The application of the high performance specific ratios is feasible in a displacement ship design. If the values of .837 lb/ft^3 and .023 ft^3/ft^3 were applied to PG-84 a weight savings of 5.47 tons and a volume reduction of 2478.4 ft^3 would result.

3.2.7.2 - FFG-7 vs. HOC

As in the case of the small ships, the hydrofoil's ship systems weight and volume fractions are lower, reflecting the specific ratios, and again indicating a lower ship impact:

		FFG-7	HOC
Ship systems sp.wt.	W_{SS}/∇	1.290 lb/ft^3	.465 lb/ft^3
Ship systems sp.vol.	V_{SS}/∇	.120 ft^3/ft^3	.057 ft^3/ft^3

- HOC's ship system specific weight is only about a third of FFG-7's. This is due in part to the high performance techniques of efficient cable routing, minimum non-structural compartmentation and other features.
- The specific weight is also low because of HOC's low specific ratios in hull structure and auxiliaries which contribute heavily to ship systems weight.

- The difference in ship systems specific volume is due primarily to FFG-7's maintenance philosophy of repair by replacement. Large accesses and passageways are required to facilitate removal and replacement of machinery and electronics. Larger ships generally have a greater percentage of volume for passageways, which may account for some of this difference.

The high performance standards can be applied to a displacement ship, resulting in a lower ship systems impact, in both weight and volume. If applied to FFG-7, the restriction imposed in passageways and access spaces may force a retooling of its maintenance philosophy. However, if other functional areas also employ high performance technology, the need for repair by replacement may be eliminated.

The application of the high performance specific ratios of .465 lb/ft^3 and .057 ft^3/ft^3 to FFG-7's ship systems would result in a weight reduction of 189.6 tons and a decrease in volume of 32,440 ft^3.

3.2.7.3 - Summary and Conclusions

- The specific ratios of the high performance ships reflect the premiums placed on excessive weight and volume in their designs.
- Application of these high performance standards to a displacement ship results in considerable weight and volume savings, with no adverse impact in other areas of performance.

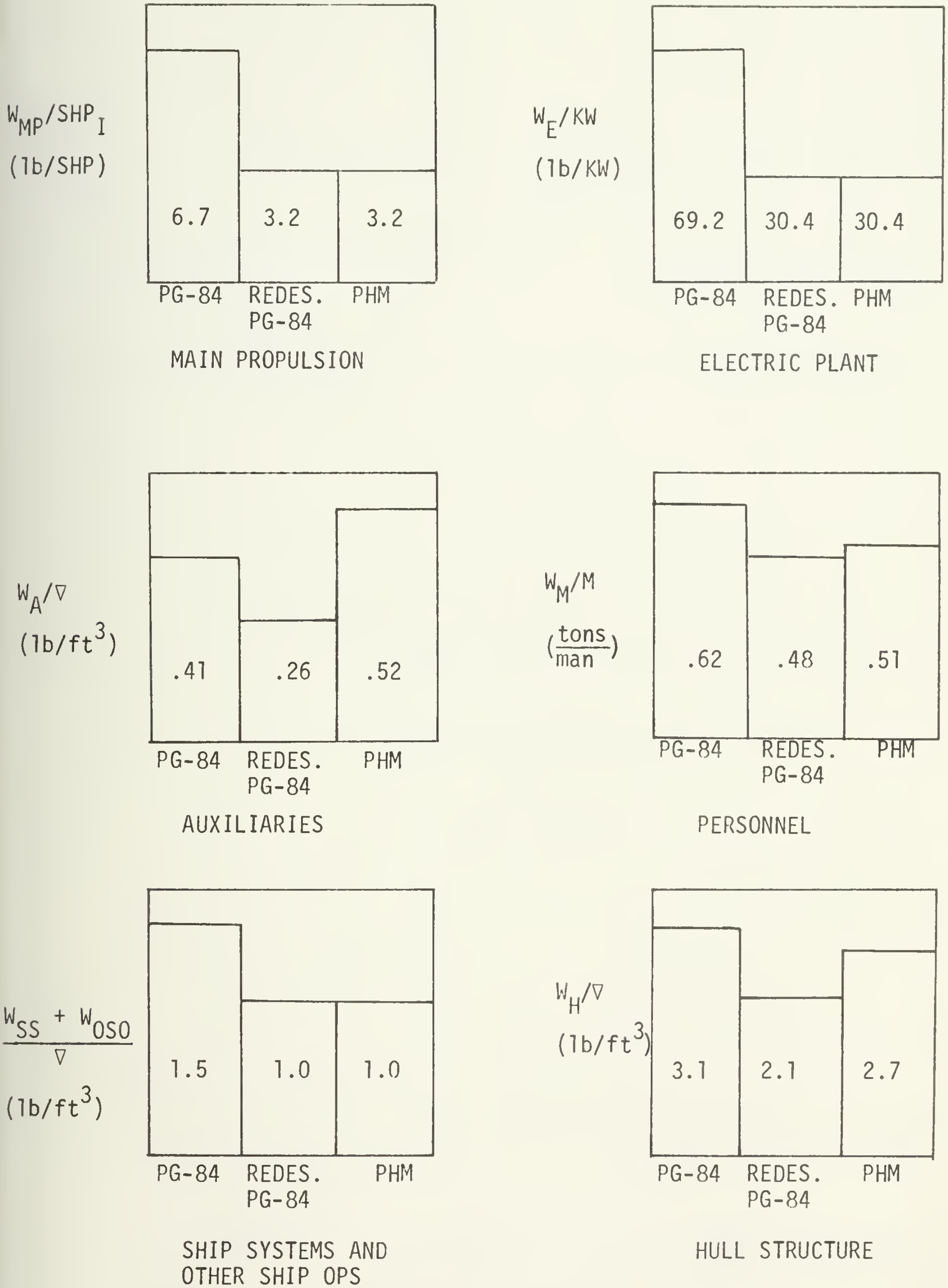

FIGURE 7 - COMPARISON OF SPECIFIC WEIGHTS - SMALL SHIPS

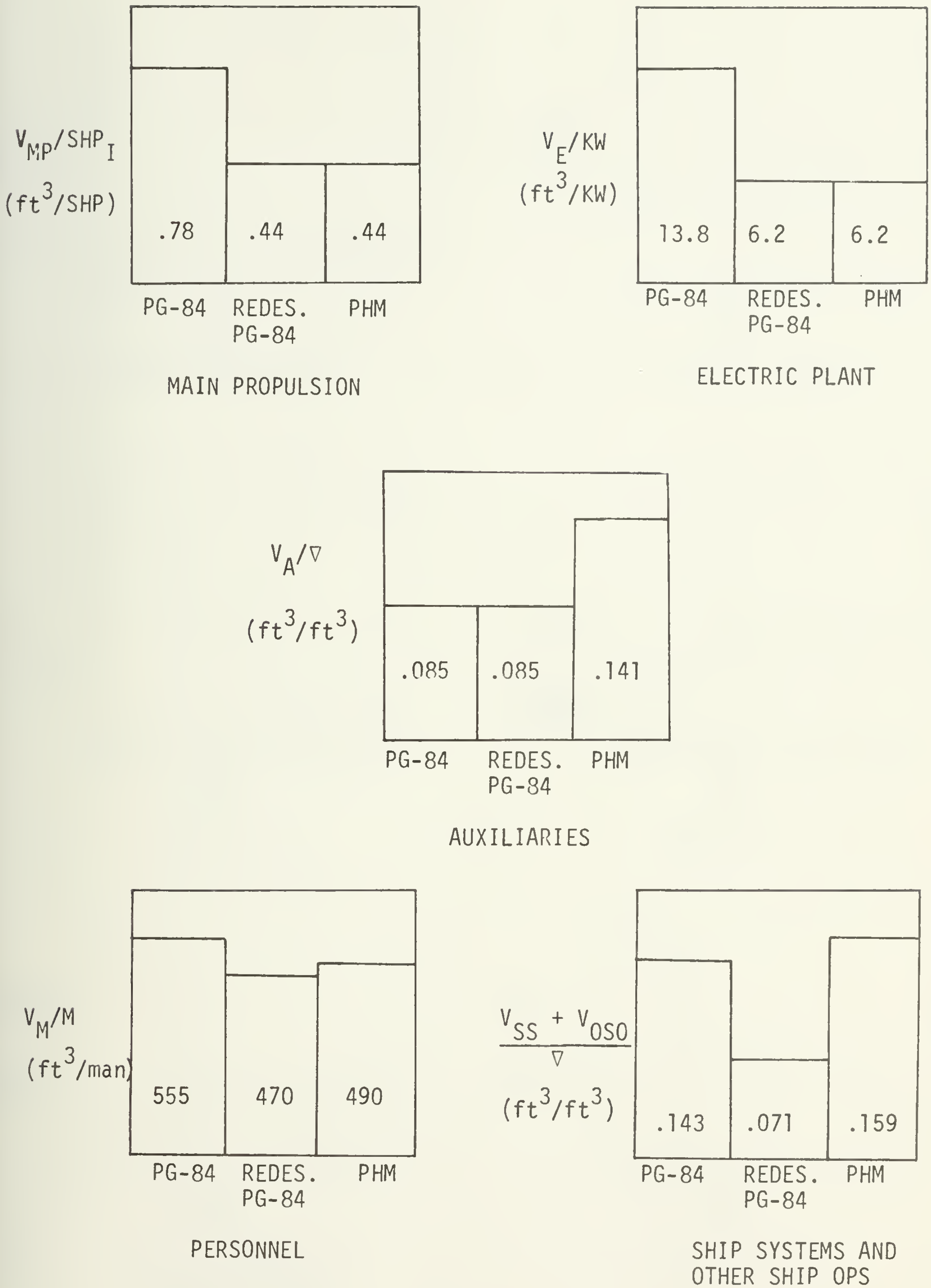

FIGURE 8 - COMPARISON OF SPECIFIC VOLUMES - SMALL SHIPS

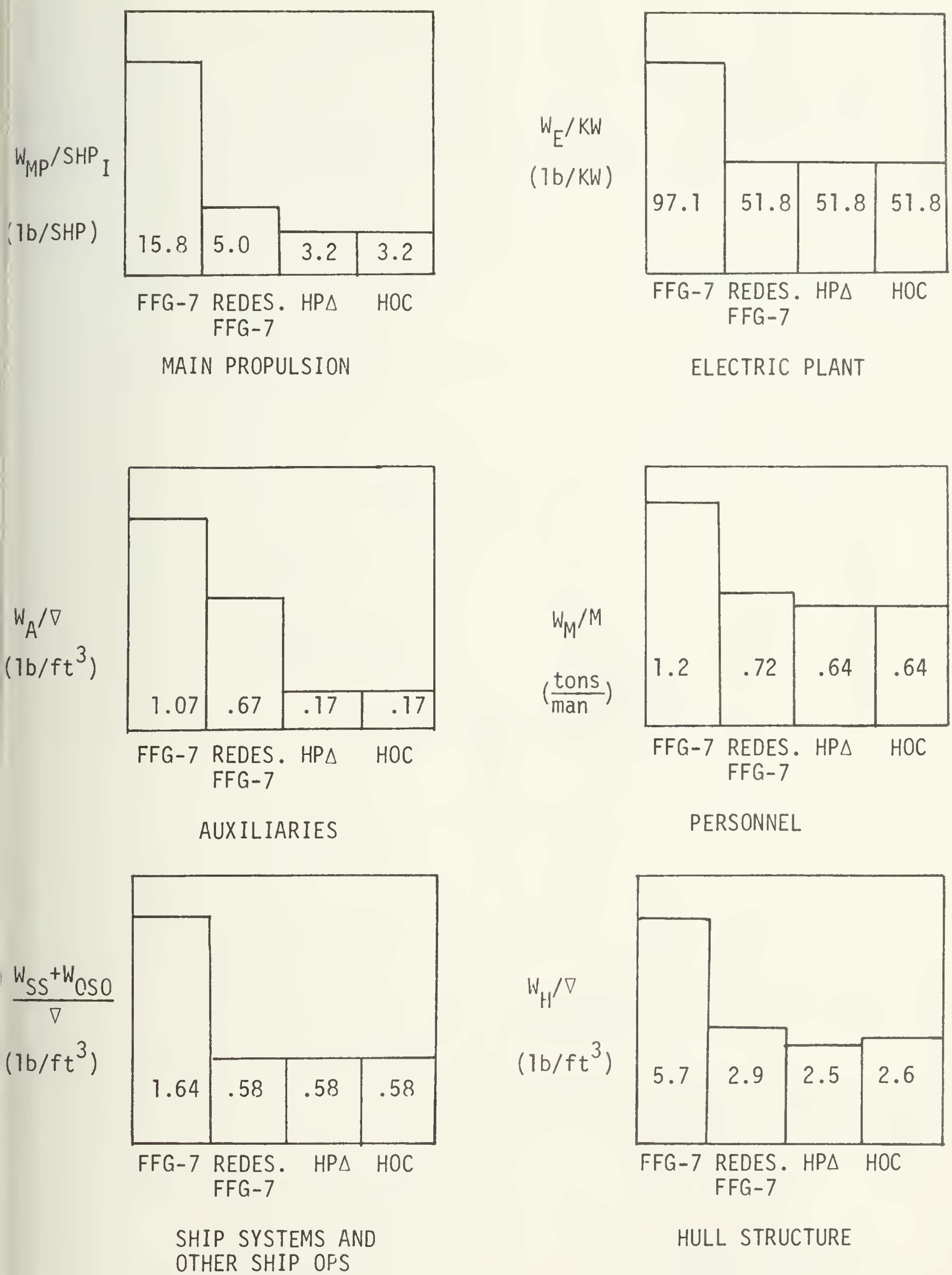

FIGURE 9 - COMPARISON OF SPECIFIC WEIGHTS - LARGE SHIPS

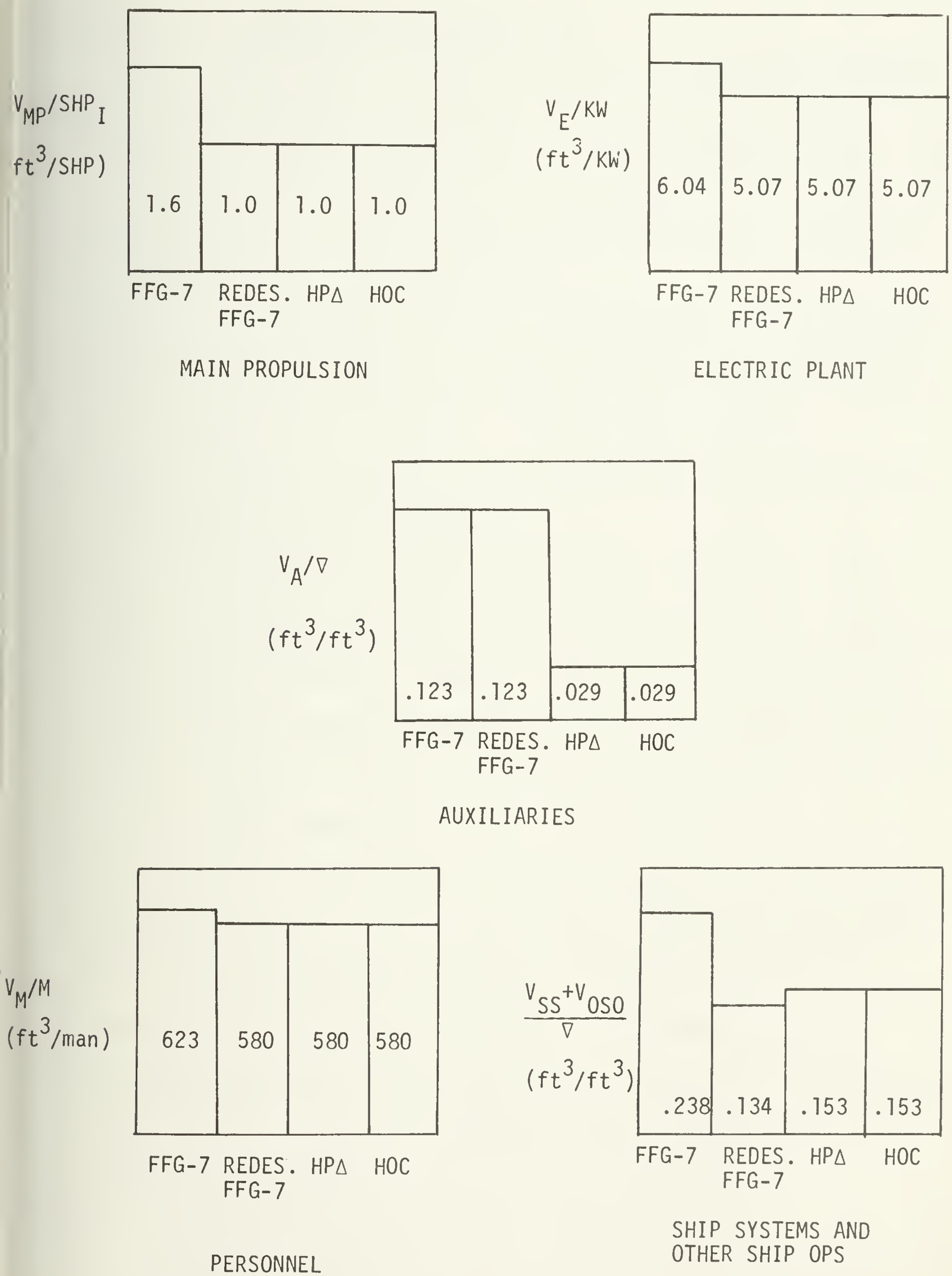

FIGURE 10 - COMPARISON OF SPECIFIC VOLUMES - LARGE SHIPS

Section 3.3 - Summary and Conclusions

In the comparison of high performance and displacement ships, several observations and conclusions can be made:

- The greatest differences in ship impact between high performance and displacement ships occur in the areas of mobility and hull structure.
- The high performance design standards cannot be applied without an assessment of their applicability to a displacement design, however. A detailed analysis of specific ships must be made before the high performance standards can be considered.
- In the mobility and electrical areas, the influence of fuel consumption plays an important role in determining the high performance impact. In spite of the fact that the high performance propulsion machinery places greater demands on fuel, the overall mobility impact is lower than in the displacement designs.
- Each of the functional categories analyzed provided the conclusion that appropriate high performance parameters could be applied to displacement ships, resulting in weight and volume savings that can be used for the incorporation of additional payload, or for increasing the installed shaft horsepower, with a corresponding increase in speed.

CHAPTER 4

THE IMPACT OF HIGH PERFORMANCE TECHNOLOGY ON NAVAL SHIP DESIGN

In the last chapter, the functional categories were analyzed individually, and appropriate specific ratios were chosen for use in a redesign of the displacement ship. Within each functional area, the high performance impact as it applied to the original displacement ship was calculated. Since each functional category was handled separately, it is the purpose of this chapter to determine the overall impact of high performance technology on Naval ship design.

Section 4.1 - Small Ship Impact

Table 16 lists the impact model inputs used in the small ship redesign. In order to reduce the number of design differences between the hydrofoil and the displacement ship, the performance requirements of the hydrofoil were used. The displacement ship was redesigned to achieve the same maximum sustained speed and the same range at high speed as PHM. The horsepower required for this speed was estimated at 19,000 SHP, as discussed in Chapter 3. A payload density of 8.80 lb/ft^3 was chosen, since this is a typical value for small ships with weapons suits similar to both PG-84 and PHM. It was determined from the model that a total enclosed volume of 46,325 ft^3 was required to accommodate the subsystems and to provide the necessary payload density. The resultant vehicle density was 11.2 lb/ft^3, the same as the original PG-84.

TABLE 16

PERFORMANCE REQUIREMENTS AND PARAMETERS FOR REDESIGNED PG-84

Item	Units	PG-84	Redesigned PG-84	PHM
W_H/∇	lb/ft^3	3.07	2.11	2.71
W_{MP}/SHP_I	lb/SHP	6.67	3.24	3.24
W_A/∇	lb/ft^3	.407	.255	.515
W_E/KW	lb/KW	69.22	30.35	30.35
W_{SS}/∇	lb/ft^3	1.089	.837	.837
W_{OSO}/∇	lb/ft^3	.401	.158	.164
W_{HAB}/M	lb/man	887.6	834.1	915.2
$W_{MS}/(M \cdot D)$	lb/man-day	35.53	33.22	33.22
V_{MP}/SHP_I	ft^3/SHP	.78	.44	.44
V_A/∇	ft^3/ft^3	.085	.085	.141
V_E/KW	ft^3/KW	13.75	6.20	6.20
V_{SS}/∇	ft^3/ft^3	.074	.023	.023
V_{OSO}/∇	ft^3/ft^3	.069	.048	.136
V_{HAB}/M	ft^3/man	526.2	455.3	455.3
$V_{MS}/(M \cdot D)$	$ft^3/man\text{-}day$	2.08	2.08	4.89
W_F/V_F	lb/ft^3	39.73	39.73	33.08
SHP	SHP	14750(inst.)	19000	17340(inst.)
SHP_{MAR}	--	--	1.125	--
KW	KW	200	200	400
M	men	24	21	21
D	days	14	7	7
SFC	lb/HP-hr	.48	.43	.43

Table 16 (cont)

Item	Units	PG-84	Redesigned PG-84	PHM
SFCA	lb/HP-hr	.50	.85	.85
TLPE	--	--	.95	--
V	knots	~40	40+	40+
R	n.miles	500(est)	700+	700(est)
Δ	tons	241.86	231.32	231.32
W_P/V_P	lb/ft^3	8.59	8.80	8.96

The redesigned PG-84's weight and volume estimates are listed in Table 17. To present a graphical comparison of the functional allocations of the three ships (PG-84, redesigned PG-84, and PHM), Figures 11 and 12 are provided. The results of the impact model show that the redesigned PG-84 has 27.9 tons more payload than PHM, and 30.7 tons more than the original PG-84. This shows very dramatically the impact of applying high performance standards to displacement designs. The payload weight of PG-84 has more than doubled, and its calm water performance has been upgraded to that of the hydrofoil.

The improved speed and endurance capability is reflected in the increased fuel fraction of the redesigned PG-84, which accounts for one-fourth of its full load displacement. It is important to realize, however, that the speed and range comparability of the redesigned PG-84 and PHM is only applicable in calm water operations. The advantage of a foil system becomes quite apparent in rough water, where the displacement ship must reduce speed in order to avoid excessive acceleration and slamming. The redesign results in a tradeoff of reduced seakeeping for additional payload.

A vertical moment analysis was also performed on the redesigned displacement ship. It was determined that the additional payload weight of 30.7 tons would have to be centered 15.78 feet above PG-84's baseline in order to prevent any change in the ship's stability characteristics. For comparison, the original payload of 29.4 tons is located with a center of gravity of 15.21 feet.

TABLE 17

REDESIGNED PG-84 WEIGHT AND VOLUME ESTIMATE

WEIGHTS

	Weight (tons)	Allocation (%)
Hull Structure	43.64	18.9
Main Propulsion	30.92	13.4
Auxiliaries	5.27	2.3
Electric Plant	2.71	1.2
Other Ship Operations	3.27	1.4
Ship Systems	17.31	7.5
Fuel	58.05	25.1
Habitability	7.82	3.4
Personnel Stowage	2.18	0.9
Payload	60.15	26.0
Displacement	231.32	100

VOLUMES

	Volume (ft^3)	Allocation (%)
Main Propulsion	9405.0	20.3
Auxiliaries	3937.6	8.5
Electric Plant	1240.0	2.7
Other Ship Operations	2223.6	4.8
Ship Systems	1065.5	2.3
Fuel	3272.9	7.1
Habitability	9561.3	20.6
Personnel Stowage	305.8	0.7
Payload	15313.3	33.1
Total Enclosed Volume	46325	100

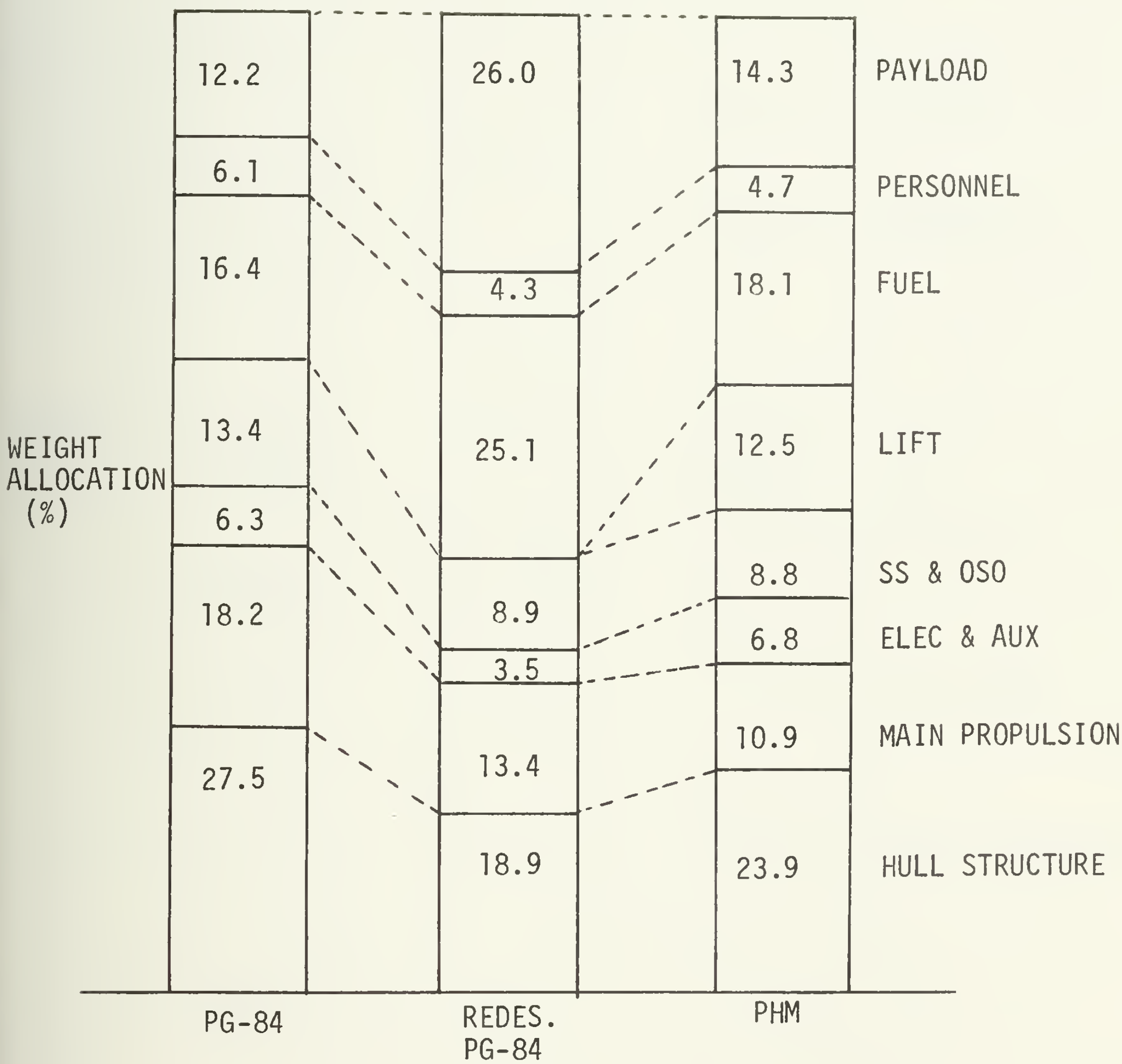

FIGURE 11 - WEIGHT ALLOCATION - REDESIGNED PG-84

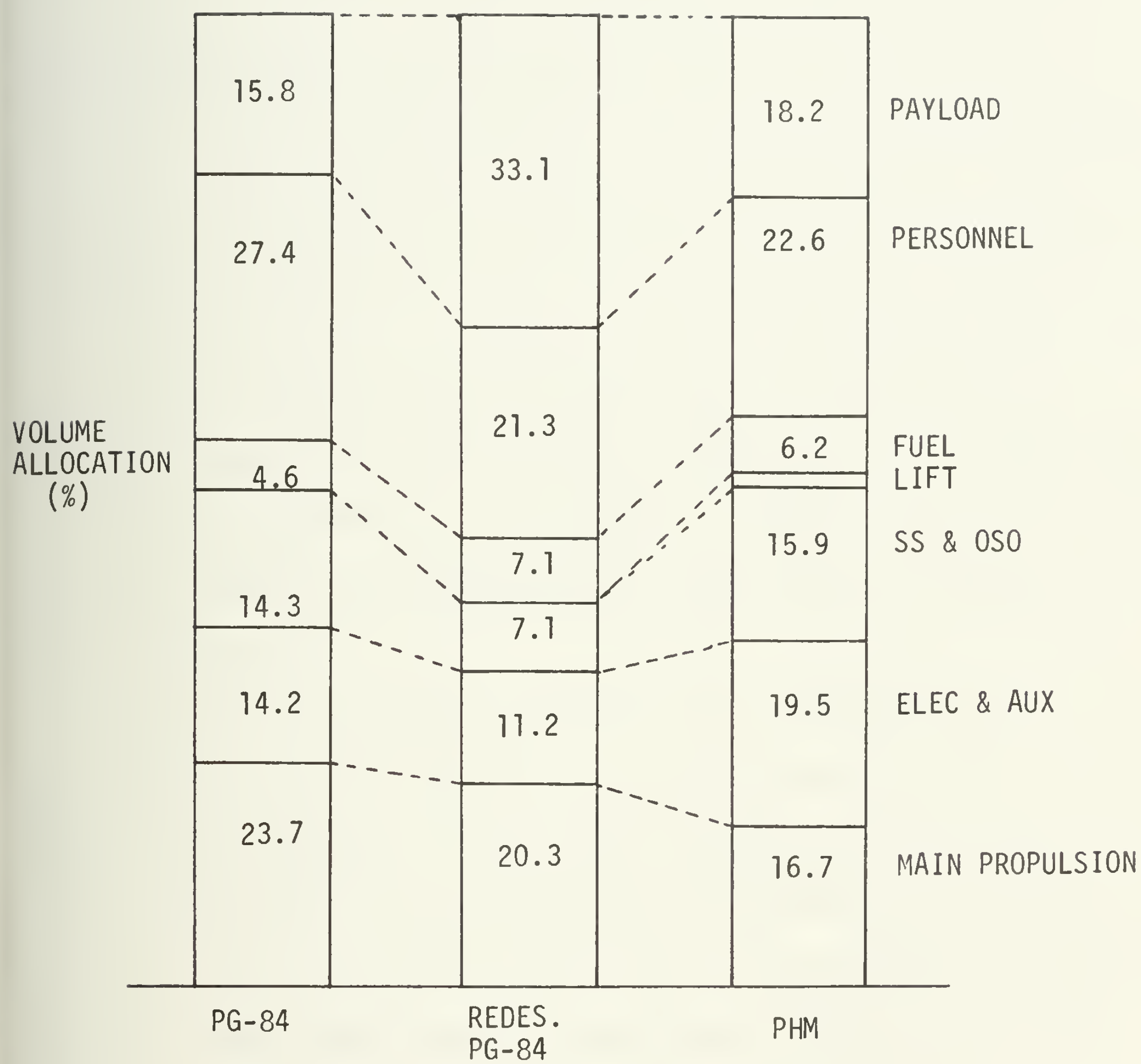

FIGURE 12 - VOLUME ALLOCATION - REDESIGNED PG-84

Section 4.2 - Large Ship Impact

Several methods were used to determine the high performance impact on large ship designs. Two redesigns were produced for FFG-7. It was redesigned to determine the maximum speed that could be attained by the application of high performance standards while maintaining a fixed payload fraction. Since the hull form remained unchanged, the increase in speed resulted from using the reallocated weight and volume for the installation of additional main propulsion machinery and the accommodation of the resulting increase in fuel.

FFG-7 was also redesigned to determine the maximum payload capacity that could be achieved while keeping the original machinery plant and, consequently, the original speed characteristics.

In order to provide a side-by-side comparison of performance features and design requirements, similar to the small ship analysis, a 1276 ton displacement ship was designed to HOC standards. This comparison provides an assessment of the foil impact on HOC's design and the resultant tradeoffs that are considered when a displacement ship is designed with comparable performance features.

The results of two studies of displacement ships designed to high performance standards are also discussed in this section. The first study used a ship synthesis model to design a high performance frigate with FFG-7's payload suit,

installed horsepower, crew size, and generator capacity. The second study is a conceptual design of a 2200 ton displacement ship employing high performance design indices and performance requirements.

4.2.1 - Redesign of FFG-7

Table 18 lists the input data used in the impact model. In both of the redesigns, FFG-7's vehicle density was left unchanged. This was necessary for two reasons. First, in redesigning for speed, unless the vehicle density is known, an evaluation of available mobility weight and volume cannot be made using the parametric model of this study. Second, in redesigning for payload, if the total enclosed volume is not specified, the model will iterate to accommodate the required payload density, and in doing so, drive the required total enclosed volume up to over 800,000 ft^3, resulting in a vehicle density of under 10 lb/ft^3. Using the original vehicle density of FFG-7 results in a more balanced design.

Table 19 lists the weight and volume breakdowns of the redesigned FFG-7's. The results are graphically displayed in Figures 13 and 14. The ship designed for speed was developed by inputting HOC's payload weight and volume fractions and FFG-7's original vehicle density of 15.8 lb/ft^3. The hydrofoil's stores endurance period and range at maximum speed were also used. After calculating the weight and volume requirements of other functional categories, it was determined that 2029.67 tons and 129,454.4 ft^3 were available for mobility

TABLE 18

PERFORMANCE REQUIREMENTS AND PARAMETERS FOR REDESIGNED FFG-7

Item	Units	FFG-7	Redesigned FFG-7	HOC
W_H/∇	lb/ft^3	5.73	2.86	2.55
W_{MP}/SHP_I	lb/SHP	15.80	5.00	3.24
W_A/∇	lb/ft^3	1.071	.672	.167
W_E/KW	lb/KW	97.12	51.82	51.82
W_{SS}/∇	lb/ft^3	1.290	.465	.465
W_{OSO}/∇	lb/ft^3	.349	.114	.114
W_{HAB}/M	lb/man	1391.4	825.2	594.7
$W_{MS}/(M \cdot D)$	lb/man-day	26.52	26.52	27.81
V_{MP}/SHP_I	ft^3/SHP	1.60	1.00	1.00
V_A/∇	ft^3/ft^3	.123	.123	.029
V_E/KW	ft^3/KW	6.04	5.07	5.07
V_{SS}/∇	ft^3/ft^3	.120	.057	.057
V_{OSO}/∇	ft^3/ft^3	.118	.077	.096
V_{HAB}/M	ft^3/man	544.7	529.8	529.8
$V_{MS}/M \cdot D$	ft^3/man	1.75	1.67	1.67
W_F/V_F	lb/ft^3	43.84	44.25	44.25
SHP	SHP	33280	33280*	--
SHP_{MAR}	--	--	1.125**	--
SHP_I	SHP	40000	40000*	47000
KW	KW	4000	4000	1500
M	men	176	176	87
D	days	45	30	30

Table 18 (cont)

Item	Units	FFG-7	Redesigned FFG-7	HOC
SFC	lb/HP-hr	.43	.43	.43
SFCA	lb/HP-hr	.44	.82	.82
TLPE	--	--	.95	--
V	knots	28+	28+*	40+
R	n.miles	2000(est)	2000+	2500(est)
Δ	tons	3585.4	3585.4	1275.9
W_P/Δ	%	9.3	10.9**	10.9
V_P/∇	%	19.0	25.4**	25.4
∇	ft^3	514922	514922	227098

*for payload redesign;not an input for speed redesign

**for speed redesign;not an input for payload redesign

TABLE 19

REDESIGNED FFG-7 WEIGHT AND VOLUME ESTIMATE

FFG-7 REDESIGNED FOR SPEED

WEIGHTS

	Weight (tons)	Allocation (%)
Hull Structure	657.45	18.3
Main Propulsion	175.78	4.9
Auxiliaries	154.48	4.3
Electric Plant	92.54	2.6
Other Ship Operations	26.21	0.7
Ship Systems	106.89	3.0
Fuel	1012.17	28.2
Habitability	64.84	1.8
Personnel Stowage	62.51	1.7
Payload	1232.53	34.4
Displacement	3585.4	100

VOLUMES

	Volume (ft^3)	Allocation (%)
Main Propulsion	78750.0	15.3
Auxiliaries	63335.4	12.3
Electric Plant	20280.0	3.9
Other Ship Operations	39649.0	7.7
Ship Systems	29350.6	5.7
Fuel	51237.3	10.0
Habitability	93244.8	18.1
Personnel Stowage	8817.6	1.7
Payload	130257.3	25.4
Total Enclosed Volume	514922	100

Table 19 (cont)

FFG-7 REDESIGNED FOR PAYLOAD

WEIGHTS

	Weight (tons)	Allocation (%)
Hull Structure	657.45	18.3
Main Propulsion	89.29	2.5
Auxiliaries	154.48	4.3
Electric Plant	92.54	2.6
Other Ship Operations	26.21	0.7
Ship Systems	106.89	3.0
Fuel	699.79	19.5
Habitability	64.84	1.8
Personnel Stowage	62.51	1.7
Payload	1631.40	45.5
Displacement	3585.4	100

VOLUMES

	Volume (ft^3)	Allocation (%)
Main Propulsion	40000.0	7.8
Auxiliaries	63335.4	12.3
Electric Plant	20280.0	3.9
Other Ship Operations	39649.0	7.7
Ship Systems	29350.6	5.7
Fuel	35424.3	6.9
Habitability	93244.8	18.1
Personnel Stowage	8817.6	1.7
Payload	184820.3	35.9
Total Enclosed Volume	514922	100

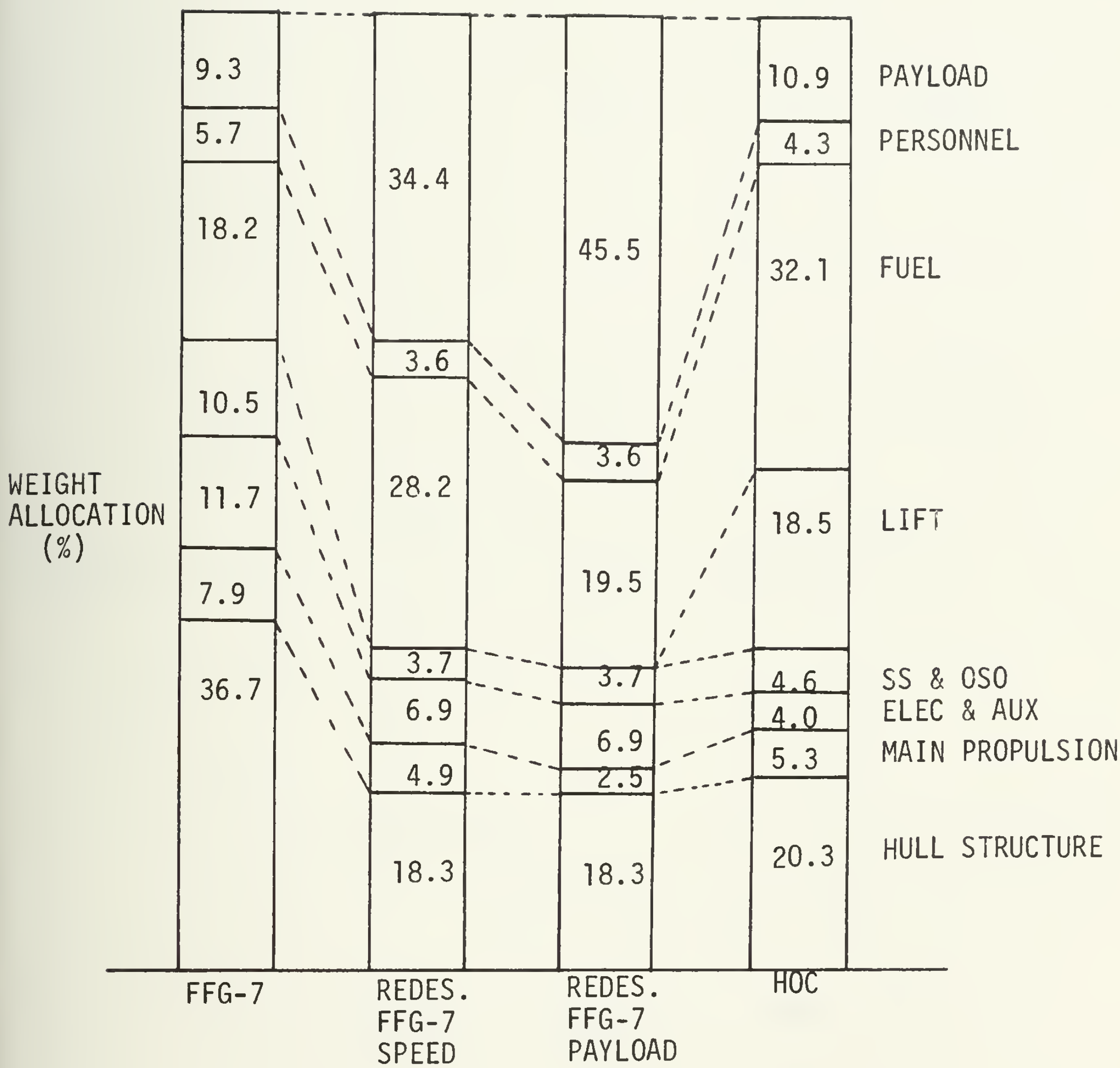

FIGURE 13 - WEIGHT ALLOCATION - REDESIGNED FFG-7

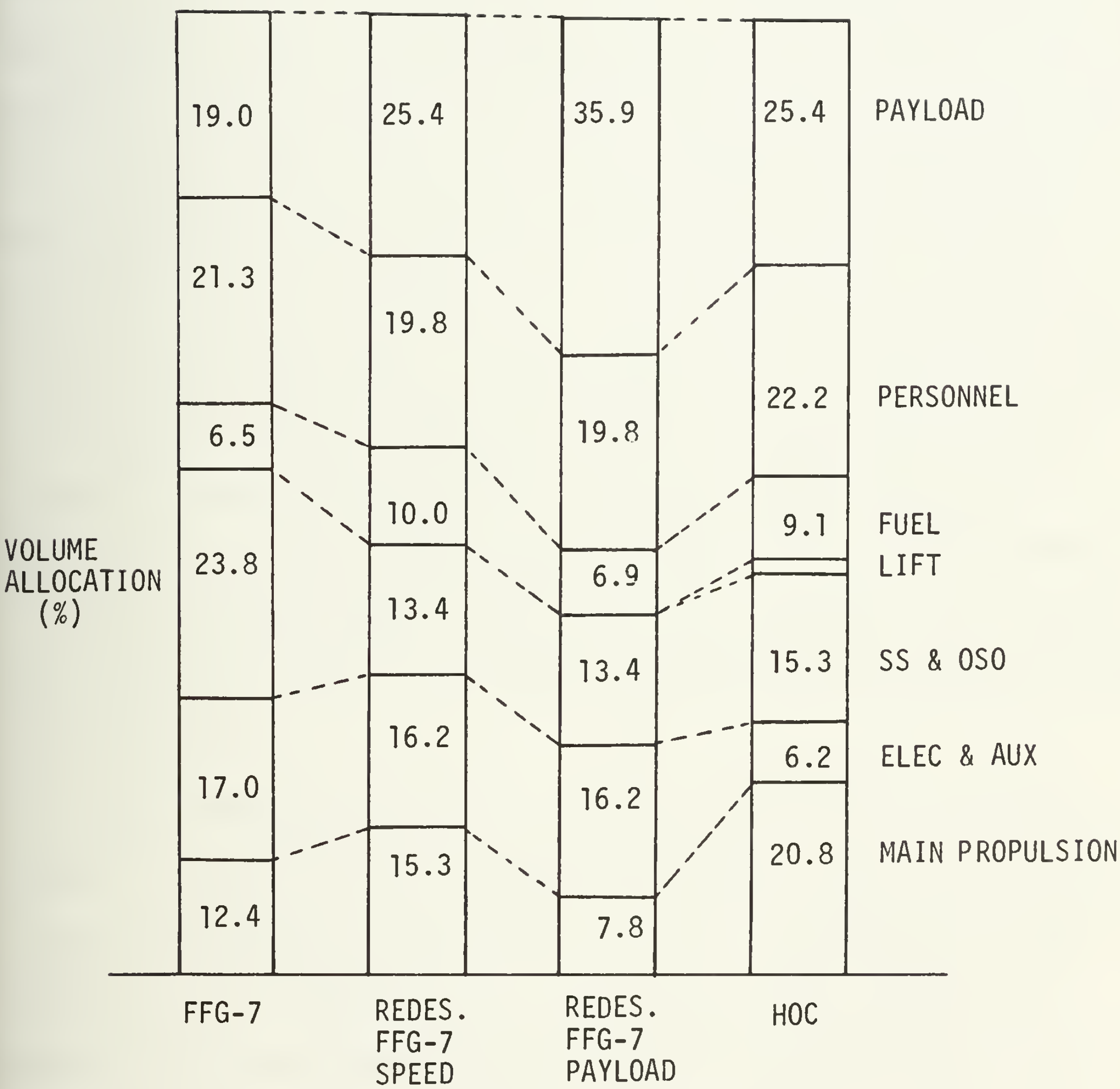

FIGURE 14 - VOLUME ALLOCATION - REDESIGNED FFG-7

(main propulsion and fuel). The powering estimate for FFG-7 at high speeds is presented in Figure 15. Since the speeds under consideration were in excess of the Taylor Standard Series values for FFG-7's hull form, the estimate was based on a fourth power extrapolation from FFG-7's maximum sustained speed of about 28 knots. By choosing a shaft horsepower and its corresponding velocity, and applying the equations for main propulsion and fuel weight and volume, the required mobility weight and volume for a given speed was calculated. It was determined that a shaft horsepower of 70,000 SHP would result in a mobility volume equal to the available volume. Since the required mobility weight for this horsepower is 841.7 tons less than the available weight, this difference is applied to payload, increasing the payload weight fraction from 10.9% to 34.4%. The maximum sustained speed that results is 34.7 knots.

The powering estimate is quite conservative, however, since it used HOC's propulsive coefficient and assumed that it was constant with velocity. Also,the speed-power curve used is overly pessimistic at higher speeds. Mandel[15] showed that for speed-length ratios of greater than about 1.6, the total resistance, and consequently the required shaft horsepower, is considerably less than a fourth power estimate. If this is taken into account, it is estimated that 70,000 SHP would result in a maximum sustained speed of about 39 knots for the redesigned FFG-7.

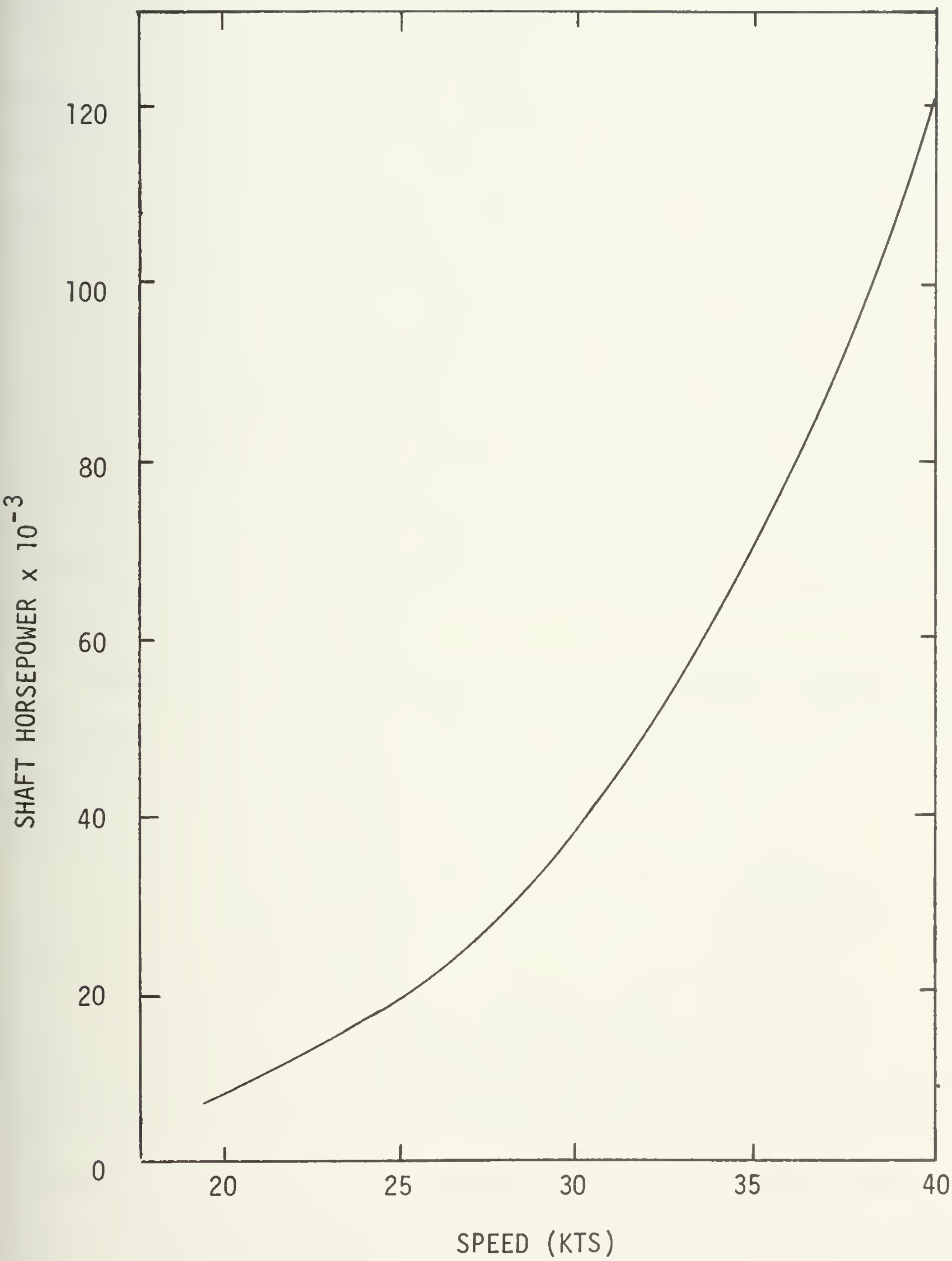

FIGURE 15 - FFG-7 SHAFT HORSEPOWER ESTIMATE AT HIGH SPEEDS[1]

The FFG-7 redesigned for payload resulted in a ship with a 45.5% payload weight fraction and a payload volume fraction of almost 39%. The fuel fractions are higher than the original FFG-7 because of the longer range required at the maximum sustained speed. The low weight impact associated with the aluminum hull is largely responsible for the high payload weight fraction. The vertical moment analysis placed this additional 1296.2 tons of payload at a central height of 19.36 feet to prevent stability degradation. This compares with the original payload of 335.2 tons at 29.93 feet. Much of this payload budget would be required for supporting functions, such as additional manning and electrical power generation, and must be taken into consideration in assessing these payload fractions.

Neither of these designs are considered feasible or desirable, but they do serve to indicate the great impact that high performance technology could make.

4.2.2 - Design of a 1276 Ton High Performance Displacement Ship

In order to provide a side-by-side comparison as in the case of the small ships, the 1276 ton planing hull used in the mobility analysis in Chapter 3 was designed to HOC standards. The input parameters used for the design of the high performance displacement ship (HPΔ) are presented in

Table 20. The estimate of 50,000 shaft horsepower developed in Chapter 3 was used to match HOC in calm water maximum sustained speed.

The resulting weight and volume allocations for HPΔ are listed in Table 21. The cost of HOC's foil system is apparent from the functional comparisons provided by Figures 16 and 17. HPΔ can carry 149.2 tons more payload than HOC. This is more than twice HOC's value and is achieved in spite of the increased main propulsion and fuel demanded by HPΔ to maintain HOC's high speed and endurance. Although the performance of HPΔ is equal to HOC's in calm water, its speed and seakeeping is degraded considerably in rough water, while the hydrofoil's sustension system provides a high level of operability. As in the case of the small ships, the payload increase associated with HPΔ must be weighed against the superior rough water performance of HOC.

4.2.3 - Other Studies

Two studies related to, but not part of, this thesis were conducted to determine the feasibility of applying high performance technology to a large displacement ship. The first one employed a versitile ship synthesis model,[16] which is capable of producing a conceptual design from specified performance requirements, weapons systems, and design indices. Although it is not tailored to input all of the parameters that were developed for the impact model, it is still useful

TABLE 20

PERFORMANCE REQUIREMENTS AND PARAMETERS FOR

A 1276 TON HIGH PERFORMANCE DISPLACEMENT SHIP

Item	Units	HPΔ	HOC
W_H/∇	lb/ft^3	2.52	2.55
W_{MP}/SHP_I	lb/SHP	3.24	3.24
W_A/∇	lb/ft^3	.167	.167
W_E/KW	lb/KW	51.82	51.82
W_{SS}/∇	lb/ft^3	.465	.465
W_{OSO}/∇	lb/ft^3	.114	.114
W_{HAB}/M	lb/man	594.7	594.7
$W_{MS}/(M \cdot D)$	lb/man-day	27.81	27.81
V_{MP}/SHP_I	ft^3/SHP	1.00	1.00
V_A/∇	ft^3/ft^3	.029	.029
V_E/KW	ft^3/KW	5.07	5.07
V_{SS}/∇	ft^3/ft^3	.057	.057
V_{OSO}/∇	ft^3/ft^3	.096	.096
V_{HAB}/M	ft^3/man	529.8	529.8
$V_{MS}/(M \cdot D)$	ft^3/man-day	1.67	1.67
W_F/V_F	lb/ft^3	44.25	44.25
SHP	SHP	50,000	47,000(inst)
SHP_{MAR}	--	1.125	--
KW	KW	1500	1500
M	men	87	87
D	days	30	30

Table 20 (cont)

Item	Units	HPΔ	HOC
SFC	lb/HP-hr	.43	.43
SFCA	lb/HP-hr	.82	.82
TLPE	--	.95	--
V	knots	40+	40+
R	n.miles	2000+	2500(est)
Δ	tons	1275.9	1275.9
∇	ft^3	227098	227098

TABLE 21

1276 TON HIGH PERFORMANCE DISPLACEMENT SHIP

WEIGHT AND VOLUME ESTIMATE

WEIGHTS

	Weight(tons)	Allovation (%)
Hull Structure	255.49	20.0
Main Propulsion	81.36	6.4
Auxiliaries	16.93	1.3
Electric Plant	34.70	2.7
Other Ship Operations	11.56	0.9
Ship Systems	47.14	3.7
Fuel	485.17	38.0
Habitability	23.10	1.8
Personnel Stowage	32.40	2.5
Payload	288.05	22.6
Displacement	1275.9	100

VOLUMES

	Volume (ft^3)	Allocation (%)
Main Propulsion	56250.0	24.8
Auxiliaries	6585.8	2.9
Electric Plant	7605.0	3.3
Other Ship Operations	21801.4	9.6
Ship Systems	12944.6	5.7
Fuel	24560.0	10.8
Habitability	46092.6	20.3
Personnel Stowage	4358.7	1.9
Payload	46899.9	20.7
Total Enclosed Volume	227098.0	100

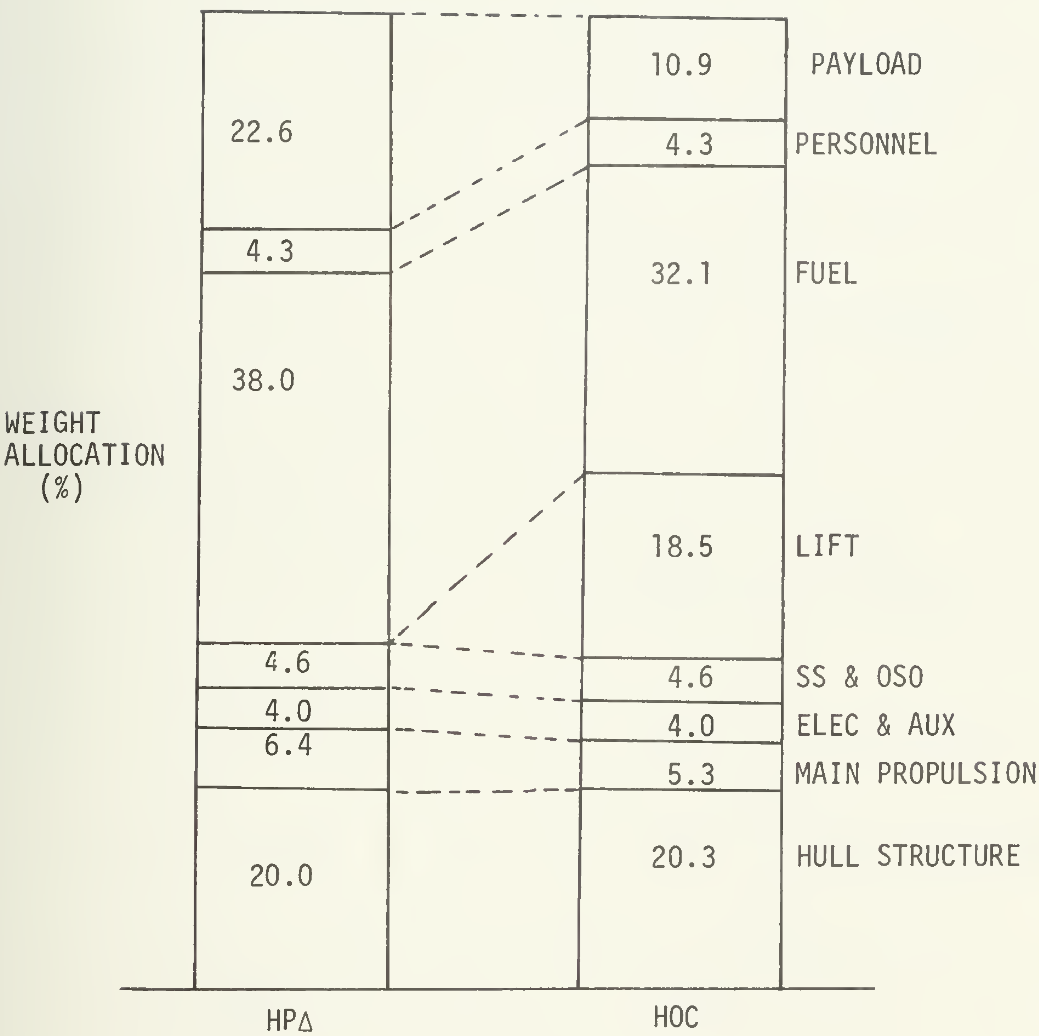

FIGURE 16 - WEIGHT ALLOCATION - HPΔ

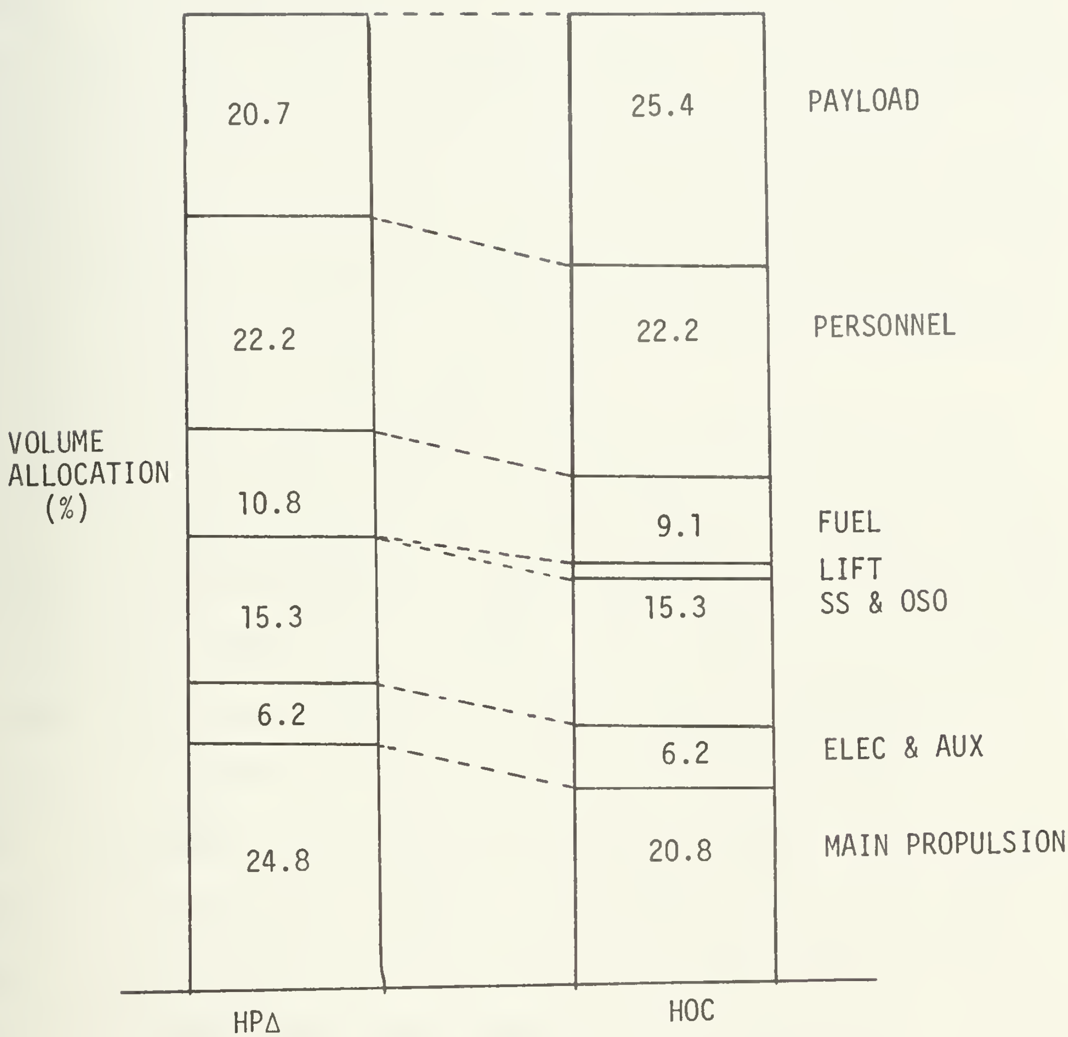

FIGURE 17 - VOLUME ALLOCATION - HPΔ

in evaluating the general influence of designing to high performance standards. FFG-7 was chosen as the baseline ship, and the model produced a high performance frigate with FFG-7's payload, installed horsepower, electric plant capacity, crew size, range, and stores endurance period. The characteristics of the high performance frigate are listed in Table 22. An aluminum hull was specified for the high performance frigate; a 50% reduction in main propulsion specific weight and a 10% reduction in main propulsion specific volume, as compared to the original FFG-7, were also used.

Unlike the impact model presented in Chapter 2, the synthesis model redesigns the hull, allowing changes in displacement and configuration, and validates such design elements as stability, large object space, deck area, and ship motion.

The resultant high performance frigate displaces 2634 tons and is capable of attaining a sustained speed of 33.0 knots. Because it is smaller than the original FFG-7, its payload fractions are higher. Although it does not match the speed or the payload fractions of the impact model's FFG-7's, it is a balanced design and does provide a realistic evaluation of the impact of high performance technology on Naval ship design.

The second study was the development of a conceptual design plan for a 2200 ton high performance displacement vessel (HPDV).[17] This study resulted in a ship capable of

TABLE 22

HIGH PERFORMANCE FRIGATE CHARACTERISTICS

Displacement	2634 tons
Total enclosed volume	392,500 ft^3
Length (at waterline)	382 feet
Beam	40.2 feet
Draft	13.4 feet
Main engines	2-LM2500 gas turbines
Installed shaft horsepower	40,000 SHP
Propulsor	1-CRPP
Speed	33.0 knots
Range	4500 n.m. @ 20 knots
Complement	185
Payload	1-76 mm Oto Melara gun 1-MK13 missile launcher 2-SH2D LAMPS helicopters 2-triple torpedo tubes 1-20 mm CIWS SQS-56 sonar MK92 FCS
Vehicle density	15.04 lb/ft^3
Payload density	9.66 lb/ft^3
Payload weight	362 tons
Payload volume	83,900 ft^3
Payload weight fraction	14%
Payload volume fraction	22%

a maximum sustained speed of 50 knots and a range of 2500 nautical miles at 40 knots, with a payload suit comparable to FFG-7's. The characteristics of this ship are given in Table 23. The ship was developed by applying many of the high performance subsystems used by the hydrofoils described in Chapter 3. The effort was directed towards designing a relatively small, fast displacement ship with a payload capacity comparable to the FFG-7 and the proposed 2200 ton surface effect ship. This was achieved by designing low-impact subsystems, especially main propulsion and hull structure, in order to accommodate the large fuel requirement and the payload items.

An aluminum planing hull was designed, resulting in a structural weight fraction of about 20%. The propulsion plant employed supercharged gas turbines and planetary reduction gears, enabling the compact installation of the 120,000 shaft horsepower required to maintain the design speed. The largest ship impact was the fuel weight required to attain a range of 2500 nautical miles at 40 knots. This accounted for about 40% of the full load displacement. As in the case of the high performance ship designed by the synthesis model, the payload fractions are lower than the impact model's FFG-7's and the HPΔ; this was expected, however, since the 2200 ton ship was designed with a specific payload suit, and the high performance impact resulted in the addition of fuel and not more payload.

TABLE 23

2200 TON HIGH PERFORMANCE DISPLACEMENT SHIP

CHARACTERISTICS

Displacement	2200 tons
Total enclosed volume	500,000 ft^3
Length (at waterline)	408 feet
Beam	42 feet
Draft	10 feet
Main engines	4-Supercharged LM 2500 gas turbines
Installed shaft horsepower	120,000 SHP
Propulsor	2-Semi-submerged, super-cavitating CRPP's
Speed	50 knots
Range	2500 n.m. @ 40 knots
Complement	110
Payload	1-76 mm Oto Melara gun 1-MK13 missile launcher 2-SH2D LAMPS helicopters 2-triple torpedo tubes 1-20 mm CIWS MK 86 FCS
Vehicle density	9.86 lb/ft^3
Payload density	6.22 lb/ft^3
Payload weight	250 tons
Payload volume	90,000 ft^3
Payload weight fraction	11%
Payload volume fraction	18%

Although this design is considered feasible, there are several areas of relatively high technological risk. Planetary gears have been proven feasible up to capacities of 50,000 shaft horsepower at an output of 300 revolutions per minute. HPDV requires 60,000 SHP per shaft, but the RPM required by the semi-submerged, super-cavitating propeller, is 400 revolutions per minute, thus reducing the expected loading of the gears. Dynamic stability requires a more comprehensive analysis. The effect of beam winds and high speed turning required that the ship be ballasted as loads are expended. The operability at high speed in rough water requires further investigation.

Neither of the two studies resulted in ships that matched the payload carrying capacities achieved by the impact model's high performance displacement ships. They do, however, provide credible support to the contention that the application of high performance technology to displacement ship design can result in increased performance in the areas of payload capacity and calm water speed.

Section 4.3 - Summary and Conclusions

The impact model is a parametric tool used to reallocate weight and volume by applying high performance criteria and design indices to a displacement ship. Since these high performance parameters may reduce ship impact in some functional areas, the result is a greater fraction of weight and volume available for payload or other design features.

This additional weight and volume, along with its required location to maintain constant vertical moment, comprise the budget used by the payload designer. It is realized that some of this "gross payload" must be used for the support of any additional payload items that may be incorporated. This support includes supplemental electric power generation, air conditioning, and manning.

An assessment of the small ships provided the following observations and conclusions:

- The redesigned PG-84 carries 84% more payload than PHM. This increase may be lessened somewhat by the necessity of additional payload support items.
- In order to achieve PHM's speed and range requirements, the redesigned PG-84 has larger main propulsion and fuel allocations than the hydrofoil.
- The comparability in speed between the redesigned PG-84 and the PHM is achieved only in calm water. PHM, because of its foil system, achieves much greater rough water performance in speed, seakeeping, and endurance.
- By reducing the number of design differences between the two ships, an assessment of military effectiveness can be made more readily.

Since there is such a great disparity in size and general characteristics between FFG-7 and HOC, results of the analysis are not as conclusive. It was shown, however, that inroads

can be made in both speed and payload-carrying capacity, when high performance design indices are applied to FFG-7. The design of the HPΔ provided a side-by-side comparison of a large hydrofoil and a high performance displacement ship. As in the case of the small ships, the major tradeoff that results is increased payload capacity versus improved sea-keeping in rough water.

The discussion of the high performance frigate and the 2200 ton high performance displacement vessel showed that the application of high performance technology to displacement ship designs can result in a considerable improvement in both speed and payload-carrying capacity, as compared to conventional designs. Although the upgrading of design features is not as dramatic for these ships as in the case of the impact model results, these studies provide validation and support of the analytical procedures presented in Chapter 2 and the selection of parameters made in Chapter 3.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

High performance ships in general, and hydrofoils in particular, have superior speed and seakeeping characteristics when compared to displacement ships with similar mission capabilities and size. The design of low ship-impact subsystems allows a high performance ship to install more horsepower than a displacement ship of similar size, and to absorb the impact of its sustension system, while maintaining a favorable payload-carrying capacity. The calm water speed advantage is achieved by this increased horsepower while the sustension system provides the rough water advantage. The application of high performance technology in these low-impact subsystems results in a considerable number of design differences between displacement ships and high performance vehicles.

If this high performance technology could be applied to a displacement ship, thus eliminating the attendant demand of the sustension system, a great deal of weight and volume would be available for increased payload, higher calm water speed, or the improvement of any of the other basic ship performance features. The use of high performance design standards cannot be made in a wholesale manner, however. Careful analysis is required to determine the applicability, feasibility, and desirability of the high performance parameters.

The design of a displacement ship to high performance design requirements and parameters reduces the number of design differences between high performance and displacement ships. This facilitates a systems analysis approach in assessing the relative merits of the ship types.

The proper application of high performance standards to a displacement design results in a ship with more payload than a high performance ship of comparable size and with equal calm water speed and high speed endurance and range. A large cost of achieving this payload increase is the reduction of the seakeeping ability provided by the sustension system. The operability of several other functional areas may also decrease as compared to a conventional displacement ship.

The impact of high performance technology on Naval ship design is significant. Considerable inroads can be made in displacement ship design with the proper application of high performance design criteria. The 2200 ton high performance displacement ship is an indication of the potential advantage gained from an exploitation of this technology.

The following areas are recommended for further study:

1) The examination of other high performance vehicles (SES, SWATH, AEV) in the same manner to evaluate the potentials of the vehicles and the areas of design innovation.

2) A comprehensive evaluation of how the operability of both high performance and displacement ships is influenced by the implementation of high performance technology.

3) The development of a more detailed method of evaluating the areas of stability, seakeeping, arrangements, and cost.

4) A design study in which several high performance displacement ship point-designs are produced to validate the trends pointed out in this thesis.

5) The execution of a comprehensive systems analysis which compares the military effectiveness of a conventional displacement ship, a high performance ship, and a high performance displacement ship.

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APPENDIX A

WEIGHT AND VOLUME BREAKDOWN OF FUNCTIONAL CATEGORIES

The following is the classification system used in defining the functional categories used in this analysis. Volume group numbers refer to the Proposed U.S. Navy Ship Space Classification System.[2] Weight group numbers are taken from the Ship Work Breakdown Structure.[11]

A-1 Payload

a) Communications/Detection

	GROUP	DESCRIPTION
Volume	1.1	Communications, detection, and evaluation
Weight	410	Command and control systems
	440	Exterior communications
	450	Surveillance systems (surface)
	460	Surveillance systems (underwater)
	471	Active ECM (including combination active/passive)
	472	Passive ECM
	491(.5)	Electronic test, checkout, and monitoring equipment
	498(.5)	Command and surveillance operating fluids
	499(.5)	Command and surveillance repair parts and special tools
	661*	Offices outfit and furnishings
	663	Electronics control centers furnishings

665*	Workshops, labs, test areas outfit and furnishings
672*	Storerooms and issue rooms outfit and furnishings

NOTE: A number in parentheses indicates the fraction of the weight group assigned to the functional category.

An asterisk identifies a weight group that is distributed among several functional categories in proportion to the deck area of the space.

b) Weapons

	GROUP	DESCRIPTION
Volume	1.2	Weapons
	1.3	Aviation
Weight	473	Torpedo decoys
	474	Decoys (other)
	476	Mine countermeasures
	480	Fire control systems
	491(.5)	Electronic test, checkout, and monitoring equipment
	492	Flight control and instrument landing systems
	498(.5)	Command and surveillance operating fluids
	499(.5)	Command and surveillance repair parts and special tools
	522	Sprinkler system
	542	Aviation and general purpose fuels
	543	Aviation and general purpose lubricating oil
	586	Aircraft recovery support systems

587	Aircraft launch support systems
588	Aircraft handling, servicing and storage
661*	Offices outfit and furnishings
665*	Workshops, labs, test areas outfit and furnishings
672*	Storerooms and issue rooms outfit and furnishings
710	Guns and ammunition
720	Missiles and rockets
730	Mines
740	Depth charges
750	Torpedoes
760	Small arms and pyrotechnics
780	Aircraft related weapons
790	Special purpose systems
LOADS	Ship ammunition
	Aviation ammunition
	Aircraft
	Aircraft fuel

c) Miscellaneous Payload

	GROUP	DESCRIPTION
Volume	1.4	Amphibious warfare
	1.5	Cargo transport
	1.6	Flag
	1.7	Passenger facilities
	1.8	Special missions

Weight	493	Non-combat data processing systems
	495	Integrated operational intelligence system
	544	Liquid cargo
	557	Liquid gases, cargo
	573	Cargo handling
	591	Scientific and ocean engineering systems
	592	Swimmer and diver support and protection systems
	594	Submarine rescue, salvage and survival systems
	595	Towing, launching and handling for underwater systems
	596	Handling systems for diver and submersible vehicles
	597	Salvage support systems
	673	Cargo stowage outfit and furnishings
	770	Cargo munitions

A-2 Ship's Personnel

a) Habitability

i) Living

	GROUP	DESCRIPTION
Volume	2.1	Living
Weight	521(.2)	Firemain and flushing (sea water) system
	528*	Plumbing drainage

	641	Officer berthing and messing spaces outfit and furnishings
	642	Non-commissioned officer berthing and messing spaces outfit and furnishings
	643	Enlisted personnel berthing and messing spaces outfit and furnishings
	644	Sanitary spaces and fixtures outfit and furnishings
	LOADS	Crew and effects

ii) Supporting functions

	GROUP	DESCRIPTION
Volume	2.2	Supporting functions
Weight	434	Entertainment and training systems
	439	Recording and television systems
	528*	Plumbing drainage
	593	Environmental pollution control systems
	645	Leisure and community spaces outfit and furnishings
	650	Service spaces outfit and furnishings
	661*	Offices outfit and furnishings

b) Personnel Stowage

	GROUP	DESCRIPTION
Volume	2.3	Stowage
Weight	533(.5)	Potable water
	638	Refrigerated spaces outfit and furnishings

	672*	Storerooms and issue rooms outfit and furnishings
	LOADS	Provisions and stores
		Potable water

A-3 Ship Operations

a) Control

	GROUP	DESCRIPTION
Volume	3.11	Ship control
	3.13	Damage control
	3.14	Offices
Weight	420	Navigation systems
	431	Switchbroads for I.C. systems
	432(.4)	Telephone systems
	494	Meteorological systems
	555	Fire extinguishing systems
	661*	Offices outfit and furnishings
	664	Damage control stations outfit and furnishings

b) Auxiliaries

	GROUP	DESCRIPTION
Volume	3.31 (less spaces dedicated to lift or other uniquely high performance systems)	Engineering auxiliaries
	3.32	Deck auxiliaries
	3.53	Boats and liferafts
	3.54	Motor vehicles

Weight	512(.5)	Ventilation system
	514(.5)	Air conditioning system
	516	Refrigeration system
	517	Auxiliary boilers and other heat sources
	521(.4)	Firemain and flushing (sea water) system
	531	Distilling plant
	551(.8)	Compressed air systems
	553	O_2N_2 system
	554	LP blow
	556(.8)	Hydraulic fluid system
	561	Steering and diving control systems
	562	Rudder
	566	Diving planes and stabilizing fins
	568	Maneuvering systems
	571	Replenishment-at-sea
	572	Ship stores and personnel and equipment handling
	581	Anchor handling and stowage systems
	582	Mooring and towing systems
	583	Boat handling and stowage systems
	584	Mechanically operated door, gate, ramp, turntable systems
	585	Elevating and retracting gear
	589	Miscellaneous mechanical handling systems
	598	Auxiliary systems operating fluids

c) Electric Plant

	GROUP	DESCRIPTION
Volume	3.33	Electrical systems
Weight	310	Electric power generation
	324	Switchgear and panels
	340	Power generation support systems
	398	Electric plant operating fluids
	475	Degaussing

d) Maintenance

	GROUP	DESCRIPTION
Volume	3.4	Maintenance
	3.52	Stores and supplies
Weight	199	Hull repair parts and special tools
	299	Propulsion plant repair parts and special tools
	399	Electric plant repair parts and special tools
	599	Auxiliary systems repair parts and special tools
	665*	Workshops, labs, test areas outfit and furnishings
	672*	Storerooms and issue rooms outfit and furnishings
	699	Outfit and furnishings repair parts and special tools

e) Tankage

	GROUP	DESCRIPTION
Volume	3.6	Tankage
	3.8	Unassigned

Weight	191	Ballast, fixed or fluid, and buoyancy units
	529	Drainage and ballasting system
	565	Trim and heel (roll stabilization)

A-4 Mobility

a) Main Propulsion

	GROUP	DESCRIPTION
Volume	3.12	Main propulsion control
	3.2	Main propulsion machinery
Weight	200 (less 299)	Propulsion plant
	513	Machinery space ventilation system
	534	Auxiliary steam and drains within machinery box
	639	Radiation shielding
	662	Machinery control centers furnishings

b) Fuel

	GROUP	DESCRIPTION
Volume	3.51	Liquids stowage
Weight	541	Ship fuel and fuel compensating system
	545	Tank heating
	LOADS	Endurance fuel oil
		Reserve feed water
		Lubricating oil

A-5 Ship Systems

	GROUP	DESCRIPTION
Volume	3.7	Passageways and access
Weight	321	Ship service power cable
	322	Emergency power cable system
	323	Casualty power cable system
	330	Lighting system
	432(.6)	Telephone systems
	433	Announcing systems
	435	Voice tubes and message passing systems
	436	Alarm, safety, and warning systems
	437	Indicating, order, and metering systems
	438	Integrated control systems
	511	Compartment heating system
	512(.5)	Ventilation system
	514(.5)	Air conditioning system
	521(.4)	Firemain and flushing (sea water) system
	523	Washdown system
	524	Auxiliary sea water system
	526	Scuppers and deck drains
	527	Firemain actuated services-other
	532	Cooling water
	533(.5)	Potable water
	535	Auxiliary steam and drains outside machinery box
	536	Auxiliary fresh water cooling

551(.2)	Compressed air systems
552	Compressed gases
556(.2)	Hydraulic fluid system
558	Special piping systems
610	Ship fittings
620	Hull compartmentation
631	Painting
632	Zinc coating
633	Cathodic protection
634	Deck covering
635	Hull insulation
636	Hull damping
637	Sheathing
671	Lockers and special stowage outfit and furnishings
698	Outfit and furnishings operating fluids

A-6 Structures

	GROUP	DESCRIPTION
Weight	100 (less 191,199)	Hull structure

A-7 High Performance (Lift) Systems

Volume	Spaces dedicated to high performance (lift) systems	Foil retraction machinery rooms, etc.
Weight	567	Lift systems

APPENDIX B

PARAMETERS USED IN IMPACT STUDY

DEFINITION	NAME	UNITS
W_P/Δ	Payload weight fraction	%
V_P/∇	Payload volume fraction	%
W_P/V_P	Payload density	lb/ft^3
W_{MB}/Δ	Mobility weight fraction	%
W_{MP}/Δ	Main propulsion weight fraction	%
W_F/Δ	Fuel system weight fraction	%
V_{MB}/∇	Mobility volume fraction	%
V_{MP}/∇	Main propulsion volume fraction	%
V_F/∇	Fuel system volume fraction	%
E_{MB}/KW	Mobility energy fraction	%
M_{MB}/M	Mobility manning fraction	%
W_{MP}/SHP_I	Mobility specific weight	lb/SHP
W_{230}/SHP_I	Prime mover specific weight	lb/SHP
W_{240}/SHP_I	Transmission specific weight	lb/SHP
W_{241}/SHP_I	Reduction gears specific weight	lb/SHP
W_{242}/SHP_I	Clutches and couplings specific weight	lb/SHP
$W_{243-247}/SHP_I$	Shafting and propulsors specific weight	lb/SHP
$W_{250-260}/SHP_I$	Propulsion support systems specific weight	lb/SHP
W_{298}/SHP_I	Main propulsion operating fluids specific weight	lb/SHP
V_{MP}/SHP_I	Main propulsion specific volume	ft^3/SHP

W_F/V_F	Fuel system density	lb/ft^3
SHP_I/Δ	Main propulsion capacity-ship size ratio	SHP/ton
W_H/Δ	Hull structure weight fraction	%
$W_{110-140}/\Delta$	Basic hull weight fraction	%
W_{150}/Δ	Superstructure weight fraction	%
$W_{160-170}/\Delta$	Masts and special structures weight fraction	%
W_{180}/Δ	Foundations weight fraction	%
W_{198}/Δ	Free flooding liquids weight fraction	%
W_H/∇	Hull structure specific weight	lb/ft^3
$W_{110-140}/V_{BH}$	Basic hull specific weight	lb/ft^3
W_{150}/V_{SST}	Superstructure specific weight	lb/ft^3
$W_{160-170}/\nabla$	Masts and special structures specific weight	lb/ft^3
$W_{180}/W_{200-700}$	Foundations specific weight	lb/ton
Δ/∇	Vehicle density	lb/ft^3
W_M/Δ	Personnel weight fraction	%
W_L/Δ	Living weight fraction	%
W_S/Δ	Personnel support weight fraction	%
W_{MS}/Δ	Personnel stowage weight fraction	%
V_M/∇	Personnel volume fraction	%
V_L/∇	Living volume fraction	%
V_S/∇	Personnel support volume fraction	%
V_{MS}/∇	Personnel stowage volume fraction	%
M_M/M	Personnel personnel fraction	%

E_M/KW	Personnel energy fraction	%
W_M/M	Personnel specific weight	lb/man
W_{HAB}/M	Habitability specific weight	lb/man
W_L/M	Living specific weight	lb/man
W_S/M	Personnel support specific weight	lb/man
W_{MS}/MxD	Personnel stowage specific weight	lb/man-day
V_M/M	Personnel specific volume	ft^3/man
V_{HAB}/M	Habitability specific volume	ft^3/man
V_L/M	Living specific volume	ft^3/man
V_S/M	Personnel support specific volume	ft^3/man
$V_{2.21}/M$	Administrative specific volume	ft^3/man
$V_{2.22}/M$	Food preparation and handling specific volume	ft^3/man
$V_{2.23}/M$	Medical and dental specific volume	ft^3/man
$V_{2.24}/M$	Personnel services specific volume	ft^3/man
$V_{2.25}/M$	Recreation and welfare specific volume	ft^3/man
V_{MS}/MxD	Personnel stowage specific volume	ft^3/man-day
E_M/M	Personnel specific energy	KW/man
W_M/V_M	Personnel density	lb/ft^3
M/Δ	Personnel capacity-ship size ratio	men/ton

W_E/Δ	Electric plant weight fraction	%
V_E/∇	Electric plant volume fraction	%
M_E/M	Electric plant personnel fraction	%
E_E/KW	Electric plant energy fraction	%
W_E/KW	Electric plant specific weight	lb/KW
W_{310}/KW	Electric power generation specific weight	lb/KW

W_{324}/KW	Switchgear and panels specific weight	lb/KW
W_{340}/KW	Electric plant support specific weight	lb/KW
W_{398}/KW	Electric plant operating fluids specific weight	lb/KW
W_{475}/KW	Degaussing specific weight	lb/KW
V_E/KW	Electric plant specific volume	ft^3/KW
KW/Δ	Electric plant capacity-ship size ratio	KW/ton
W_A/Δ	Auxiliaries weight fraction	%
W_{510}/W_A	Climate control weight fraction	%
W_{520}/W_A	Sea water systems weight fraction	%
W_{530}'/W_A	Distilling plant weight fraction	%
W_{550}'/W_A	Air, gas, and hydraulic systems weight fraction	%
W_{560}'/W_A	Steering and maneuvering weight fraction	%
$W_{570-580}'/W_A$	Deck auxiliaries weight fraction	%
W_{590}'/W_A	Auxiliaries operating fluids weight fraction	%
V_A/∇	Auxiliaries volume fraction	%
M_A/M	Auxiliaries personnel fraction	%
E_A/KW	Auxiliaries energy fraction	%
W_A/∇	Auxiliaries specific weight	lb/ft^3
W_{510}'/∇	Climate control specific weight	lb/ft^3
W_{520}'/∇	Sea water systems specific weight	lb/ft^3
W_{530}'/M	Distilling plant specific weight	lb/man
W_{550}'/∇	Air,gas, and hydraulic systems specific weight	lb/ft^3

$W_{560'}/\Delta$	Steering and maneuvering specific weight	lb/ton
$W_{570-580'}/\Delta$	Deck auxiliaries specific weight	lb/ton
$W_{590'}/\nabla$	Auxiliaries operating fluids specific weight	lb/ft^3
V_A/∇	Auxiliaries specific volume	ft^3/ft^3
∇/Δ	Auxiliaries capacity-ship size ratio	ft^3/ton
W_{OSO}/Δ	Other ship operations weight fraction	%
V_{OSO}/∇	Other ship operations volume fraction	%
W_{OSO}/∇	Other ship operations specific weight	lb/ft^3
W_C/∇	Ship control specific weight	lb/ft^3
W_{MN}/∇	Maintenance specific weight	lb/ft^3
W_T/∇	Tankage specific weight	lb/ft^3
V_{OSO}/∇	Other ship operations specific volume	ft^3/ft^3
V_C/∇	Ship control specific volume	ft^3/ft^3
V_{MN}/∇	Maintenance specific volume	ft^3/ft^3
V_T/∇	Tankage specific volume	ft^3/ft^3
W_{SS}/Δ	Ship systems weight fraction	%
V_{SS}/∇	Ship systems volume fraction	%
W_{SS}/∇	Ship systems specific weight	lb/ft^3
V_{SS}/∇	Ship systems specific volume	ft^3/ft^3

APPENDIX C

SHIP DATA

Weights, volumes and important design features of the ships analyzed in Chapter 3 are presented for reference in this appendix.

TABLE C-1

PG-84 DATA

	Weight (tons) [12]	Volume (ft^3) [2]
Payload	29.44	7681.0
Communications/Detection	2.48	1780.2
Weapons	26.96	5900.8
Miscellaneous Payload	0.00	0.0
Ship's Personnel	14.84	13324.7
Living	7.59	10919.7
Personnel Support	1.92	1707.8
Personnel Stowage	5.33	697.3
Ship Operations	23.71	10236.9
Control	2.38	1117.3
Auxiliaries	8.83	4112.5
Electric Plant	6.18	2750.6
Maintenance	5.80	2071.5
Tankage	0.52	185.0
Mobility	83.68	13774.7
Main Propulsion	43.91	11532.4
Fuel	39.77	2242.3
Ship Systems	23.62	3578.0
Hull Structure	66.57	--
	Δ =241.86	∇ = 48596.0

Additional Data

Crew Size: 24 (3 officers, 3 CPO's, 18 enlisted)

Total Installed Horsepower: 14,750 HP

Installed Generator Capacity: 200 KW

TABLE C-2

PHM DATA

	Weight (tons) [13]	Volume (ft^3) [10]
Payload	33.10	8277
Communications/Detection	4.75	4812
Weapons	28.35	3465
Miscellaneous Payload	0.00	0
Ship's Personnel	10.76	10279
Living	6.14	8664
Personnel Support	2.44	897
Personnel Stowage	2.18	718
Ship Operations	19.23	15067
Control	2.84	1367
Auxiliaries	10.48	6412
Electric Plant	5.42	2479
Maintenance	0.49	976
Tankage	--	3833
Mobility	67.01	10463
Main Propulsion	25.09	7624
Fuel	41.92	2839
Ship Systems	17.01	1035
Hull Structure	55.18	--
Lift System	29.03	423
	Δ = 231.32	∇ = 45544

Additional Data

Crew Size	21 (4 officers, 3 CPO's, 14 enlisted)
Total Installed Horsepower	17340HP
Installed Generator Capacity	400 KW

TABLE C-3

FFG-7 DATA

	Weight (tons) [14]	Volume (ft^3) [8]
Payload	335.22	97799
Communications/Detection	54.98	37516
Weapons	280.24	60283
Miscellaneous Payload	0.00	0
Ship's Personnel	203.10	109763
Living	74.45	70073
Personnel Support	34.88	25793
Personnel Stowage	93.77	13897
Ship Operations	499.74	148211
Control	36.75	20208
Auxiliaries	246.14	63407
Electric Plant	173.43	24143
Maintenance	33.19	14375
Tankage	10.23	26078
Mobility	934.28	97250
Main Propulsion	282.18	63930
Fuel	652.10	33320
Ship Systems	296.59	61899
Hull Structure	1316.47	--
	Δ = 3585.40	∇ = 514922

Additional Data

Crew Size	176 (14 officers, 14 CPO's, 148 enlisted)
Total Installed Horsepower	40,000 HP
Installed Generator Capacity	4,000 KW

TABLE C-4

HOC DATA

	Weight (tons)[4]	Volume (ft^3)[4]
Payload	138.9	57745
Communications/Detection	55.4	30058
Weapons	83.5	27687
Miscellaneous Payload	0.0	0
Ship's Personnel	55.5	50443
Living	20.4	38018
Personnel Support	2.7	8072
Personnel Stowage	32.4	4353
Ship Operations	63.2	35961
Control	7.2	12114
Auxiliaries	16.9	6605
Electric Plant	34.7	7600
Maintenance	4.1	7451
Tankage	0.3	2191
Mobility	476.8	67882
Main Propulsion	68.0	47188
Fuel	408.8	20694
Ship Systems	47.1	2176
Hull Structure	258.7	--
Lift System	235.7	12891
	Δ = 1275.9	∇ = 227098

Additional Data

Crew Size	87 (9 officers, 9 CPO's 69 enlisted)
Total Installed Horsepower	47,000 HP
Installed Generator Capacity	1,500 KW

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